THE GLOBAL ENERGY SECTOR FROM A SUBSURFACE PERSPECTIVE

VOL. 20

GEO ExPro 3 2023

HOW TO PROMOTE UNEXPLORED AREAS?

Insights from Newfoundland and Labrador, Canada

EXPLORATION OPPORTUNITIES

Møre Basin
Norwegian Sea
Slope and basin floor plays

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Layout and Design
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Print
United Press, Latvia

GxP PUBLISHING

COVER ILLUSTRATION: ZOLTÁN SYLVESTER

The forgotten part of geothermal energy

I HAVE JUST RETURNED from the Energy Geoscience Conference in Aberdeen. Three days of conferencing in a setting where oil and gas, geothermal and CCS were discussed and presented at length. Congratulations to the organisers – GESGB and the Geological Society - for putting together a programme that reflects the disciplines many subsurface professionals now happen to find themselves working in.

The thing that I missed though, was the shallow part of the geothermal energy sector that relies on the installation of 100–300 m deep closed loops. Some may say that there is not much of a subsurface element in drilling these boreholes, but I would dispute that. As one of our articles in the Geothermal section (p. 60) shows, it is the geology that determines to a large extent how these boreholes are being drilled. It is also very intriguing to see how some companies have relentlessly optimised their drilling equipment in order to drill two holes a day where previously this was only half.

At the end of the day, it is these shallow geothermal systems that are being drilled and completed every single day now, with hopefully a steep ramp-up in activity as well. It is this part of the geothermal sector that deserves a more prominent place at subsurface conferences, even more so because deep geothermal keeps on being a matter of studies and a lack of real projects.

"...it is the geology that determines to a large extent how these boreholes are being drilled."

BEHIND THE COVER

The geographical focus of our Cover Story, the Regional Update and the Core section is the High North. And there is good reason to focus on this area, because the northeast of Canada is experiencing an exciting phase of exploration with BP and Exxon drilling wells in deep water off Newfoundland. BP's Ephesus well is targeting Eocene deep-water sandstones, which led us to this beautiful outcrop photo shown on the front cover. It is a subaqueous landslide deposit and overlying sandy turbidite of the Eocene Scripps Formation, La Jolla, California. The photo was taken by Zane Jobe from Colorado School of Mines. Please contact Zane at zanejobe@mines.edu if you'd like to book a trip in Fall 2023 to visit this outcrop and many other amazing deep-marine channel and lobe deposits in Southern California.

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OSDU update

The open-source technology is reaching critical mass and the benefits to industry are being felt.

BREAKING DOWN SILOS in the data landscape has always been a desire for oil and gas companies. OSDU is an open-source platform and reference architecture that facilitates reliable, scalable, secure and discoverable access to data. The platform originated in the Open Group forum by the major oil and gas companies and has great potential for cost savings and new and innovative ways of using subsurface data.

OSDU is a disruptive technology that is now at that critical mass state, developed and maintained by more than 200 members in the OSDU Forum. But, material is like talent: only by using it you can reap the rewards.

During the latest OSDU forum meeting in April held in London, the presentation of actual use cases showed that the first benefits and rewards are being harvested by operators and software vendors. Especially the companies with an agile "just do it" mindset show the most progress.

It is worth noting though that OSDU finds its way into organisations with enough IT and Data Operating power. In conversations with customers, it is clear that this is still one of the major barriers for smaller operators and vendors.

OSDU does force organisations into a unified horizontal data strategy and that is not coming out of the box. The good news is that the forum does not just consist of technology: integration and consultancy is often just one click away.

Michaël Van der Haven and Brian Archer, CGI
Further information at: cgi.com

PHOTOGRAPHY: ADOBE STOCK; GEOSPACE

Geospace incorporates 3C fiber optic tech into downhole solution resulting in years' long massive heat tolerance

Global energy exploration equipment manufacturer, Geospace Technologies recently spun-off technology from its OptoSeis®, three-component fiber optical sensing permanent reservoir monitoring solution, into a downhole system known as Insight™ by OptoSeis.

INSIGHT LEVERAGES the all-optic monitoring subsea and land-based systems originated by PGS and acquired by Geospace. The resulting system features three-component orthogonally arranged, optical downhole shuttles, specializing in multi-level, real-time, continuous, high-definition seismic acquisition.

"Using state of the art technology is the best way to ensure repeatable and reliable information," said Chief Project Engineer Robbin Adams. "Our company strives to deliver highly ruggedised products to enable the most informed decisions in reservoir characterization."

Downhole applications have long suffered effectiveness due to limitations in extreme heat tolerance, especially at extended duration. By eliminating electronic components and replacing them with high dynamic range optical accelerometers, Insight operates at temperatures up to 150°C for years with a maximum pressure rating of 20,000 psi. Insight's fiber optics offer the added advantage of EMI immunity. In contrast to the data received from fiber optic DAS systems, Insight's linear point sensing truly enables accurate recording of low-amplitude microseismic events.

Insight is ideal for applications such as VSP imaging, microseismicity monitoring, induced seismicity and time-lapse 4-D monitoring, check shots for seismic calibration, and drilling solutions. With increased subsurface information demands of the energy transition, areas such as geologic carbon storage monitoring will require advanced technology to withstand harsh environmental conditions for years.

Further information at: geospace.com

Earlier this spring, Insight successfully completed performance evaluations at the University of Texas-Austin's Bureau of Economic Geology Devine Geophysical Test Site.

Spinning the CCS project wheels - it's time to change gear!

The CCS project wheels are spinning – we have identified plenty of CO_2 sources, we can calculate storage capacity, injection rates and costs, and provide analysis of storage security and social licence – so we should be racing ahead, but are we actually stuck in the slow lane?

AS I WRITE, CO_2 is being injected from the Nini platform in the Danish North Sea as part of Project Greensand, the world's first cross-border offshore CO_2 storage project facilitated by INEOS and partners.

The NSTA in the UK is primed to award offshore storage licences in early 2023, after receiving interest from nineteen companies in areas off the coast of Aberdeen, Liverpool, Lincolnshire and Teeside. With this clearly defined need, combined with the will and skills to move CCS projects forward, what remains of this decade will, undoubtedly, see major growth in CO_2 storage. However, given the scale of the challenge, the reality is that we still need to change up a gear and move into the fast lane – time is of the essence.

There is clearly more to CCS than storing CO_2 underground and the need to address the geoscience, economic and social challenges is stronger than ever. As organisations look to transition into CCS projects, the decades of hard-earnt subsurface project skills and experience will undoubtedly stand the energy industry in good stead. We have the technology but do we have the willpower or the time?

Let us work together to break down the economic challenges and hit that CCS accelerator pedal!

Richard Cobb, Geologica
Further information at: geologicaworld.com

The drilling hazard that has become a prospective target

Shallow gas pockets are easy to identify on seismic, but another approach is required to further de-risk them.

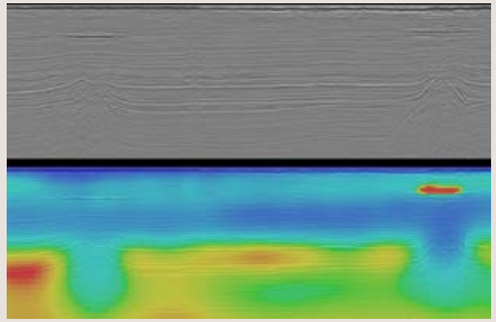
THIS YEAR'S GAS DEMAND SURGE and associated price hike have led many companies to re-initiate exploration for gas. On that basis, shallow gas accumulations have re-appeared on the global exploration radar, because in some cases there are economic quantities of gas to be produced and drilling costs are small compared to targeting HPHT prospects.

But, even though shallow gas pockets are easy to spot on conventional 2D and 3D seismic data, significant risk remains because the geophysical response of a poorly and very well-saturated shallow gas reservoir are very similar. It explains why "dry" wells can still be drilled despite the presence of a prominent seismic anomaly and even a flat spot.

In other words, a technique is required that differentiates between residual and high-saturation shallow gas pockets in the subsurface. This is where CSEM comes in, because differences in resistivity are mainly driven by the amount of brine in the sediments. And, because the CSEM signal is heavily dependent on the depth of the target, shallow gas pockets are ideally positioned to be further de-risked by this technique.

The figure below shows an example of a seismic line that clearly displays two shallow seismic anomalies. Based on this dataset alone, one would be in the dark as to which one to drill first. Subsequent screening of a CSEM line quickly shows which one to target. Therefore, a Multiphysics approach will deliver a large improvement when it comes to shallow gas prospect evaluation.

Dag Helland-Hansen, EMGS
Further information at: emgs.com



Similar seismic amplitude anomalies in the shallow subsurface show an extremely different resistivity response in CSEM data, leading to very different profiles in terms of their risk and volume expectations.

SOURCE: PIXABAY; EMGS

Retraining for CCS projects

Developing capacity for CO_2 storage in geological formations is rapidly increasing, bringing specific technical and regulatory requirements that are different from oil and gas operations.

UNDERSTANDING THE TECHNICAL AND OPERATIONAL RISKS in each component of the transport and storage system is rudimentary to CO_2 leakage prevention and system performance optimisation. For instance, injection well issues are not necessarily just solved by well engineers, but also by facility engineers who manage pressure and temperature of the CO_2 stream.

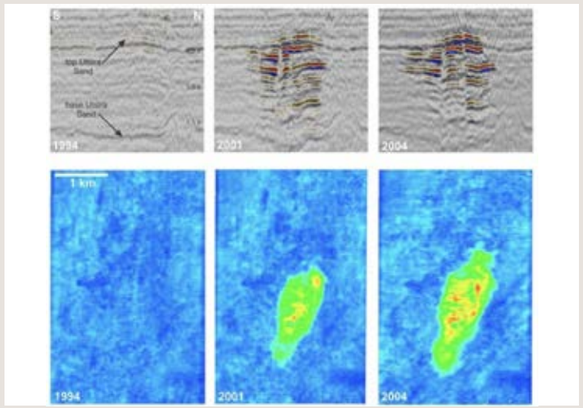
The PVT characteristics of the CO_2 stream also play an important role in the risk assessment of the transport and storage system. Unexpected CO_2 phase changes, between the super-critical, liquid, gas, and solid phases can occur in any part of the system if pressure and/or temperature of the CO_2 stream is not sufficiently controlled.

The storage development plan and site (field) management plan should be aimed at managing CO_2 leakage risks and optimising system performance during and after the injection phase of the project. This requires all surface, subsurface, and operations disciplines to understand the risks and issues of the transport and storage systems, and how they are managed.

We need to understand such things as whether long-term CO_2 exposure cause precipitation or dissolution of formation minerals. Will faults be reactivated and create permeable pathways, and could buoyancy effects transfer to shallower depth and cause leakage?

Various disciplines must be well-equipped to refocus their skills and technical priorities in order to identify all functions and associated risks of a CO_2 transport and storage system through targeted and integrated training. This is key to develop and operate the entire system safely and securely, while satisfying legal requirements and following best practices.

Peter van den Bogert, PetroEDGE
Further information at: petroedgeasia.net



Time-lapse seismic images of the Sleipner CO_2 plume in 1994, 2001 and 2004. N-S lines through the plume (top); plan view of total reflection amplitude in the plume (bottom).

It all starts at IMAGE'23

In addition to the traditional topics in petroleum geoscience, discover new content areas uncovering the hottest science, market trends, and opportunities.

THE SOCIETY OF EXPLORATION GEOPHYSICISTS (SEG) AND THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS (AAPG) in conjunction with the Society for Sedimentary Geology (SEPM) are excited to host the third annual International Meeting for Applied Geoscience and Energy (IMAGE), 28 August – 1 September in Houston, Texas at the George R. Brown Convention Center.

IMAGE '23 has been designed and built by industry professionals as the place for geoscientists, energy professionals, and thought leaders to meet and shape the future of applied geosciences and energy. It will provide an influential platform for sharing best practices, discovering solutions, and developing new perspectives and strategies to challenge and plan for what's ahead.

A traditional and forward-looking technical program of more than 1,000 presentations will inspire and encourage collaboration in areas including strategic market trends, business of applied geoscience, energy markets and finance, near-surface geophysics, energy transition and sustainability, diversity and inclusion, and government policies and regulation.

Mark your calendar and start making plans to join us in Houston!

Further information at: imageevent.org

SOURCE: CHADWICK ET AL. (2010)

Developments in seismic data processing techniques

New partnership between GeoTomo and GRCI offers a comprehensive solution for obtaining accurate earth models and images from seismic data collected in challenging environments.

DEDICATED SOFTWARE PROGRAMS employ several techniques, including non-linear traveltime tomography, land-specific FWI, bending ray Kirchhoff migration, anisotropic depth imaging, and horizon-consistent velocity modeling, to achieve obtaining accurate earth models.

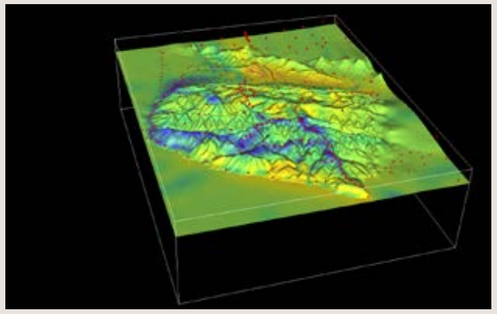
The near-surface model estimation uses nonlinear tomography, which considers topography and resolves lateral and vertical complexities. This can then be blended with the FWI solution for an integrated joint tomography/FWI velocity solution.

For land seismic acquisition, GRCI performs simultaneous source deblending, which is useful in reducing acquisition costs while improving data quality. GeoTomo has developed a methodology for deblending simultaneous source acquisition, which includes multiple source and self-sourced interference.

The methodology for vibroseis node acquisition is based on sound research and proven techniques, which involves using the residual left over after the coherent signal is re-blended and subtracted from the raw data in the common receiver domain. The method has a faster convergence compared to other approaches, especially on noisy data.

Compressive sensing reconstruction is also used, which involves using a non-uniform spacing of sources and/or receivers to estimate the complete data spectrum in an appropriate transform domain. This allows for the reconstruction of the data at a finer spacing. The software applies noise attenuation algorithms by running the compressive sensing reconstruction in the cross-spread domain, resulting in a finely sampled dataset with a regular grid.

Alan Bembridge, Geo Resources Consultancy International
Further information at: grc-international.net



SOURCE: GEO RESOURCES; ACTEQ

Advances in survey design

ACTeQ has introduced new 3D ray tracing functionality for its TesserACT survey design and optimisation software.

THE TRADITIONAL MODEL of survey design uses a survey design tool to create geometry which is passed to a different program - often Excel - to estimate cost. Iterating to find the most cost-effective survey design using this approach is slow, error-prone and often results in sub-optimum survey design.

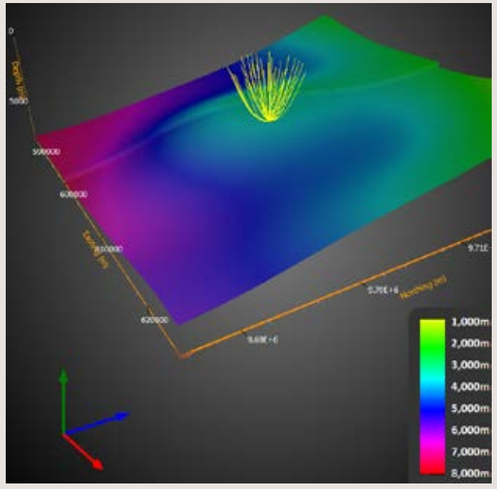
TesserACT addresses these problems by allowing a user to simultaneously define and modify geophysical and operational models. As a design is updated, the user immediately sees the changes in cost and quality.

Until now, TesserACT has focused primarily on the efficient placement of sources and receivers, and the most cost-effective acquisition sequence. 3D ray tracing capability has now been added with the introduction of Z-Design as a seamless plug-in to TesserACT.

ACTeQ's philosophy is to avoid re-inventing the wheel. A number of potential industry partners were evaluated and Houston based Z-Terra was selected as a collaboration partner. Z-Terra has provided access to 3D ray tracing technology developed over many years, allowing Z-Design to deliver advanced technology seamlessly integrated with other survey design and optimisation functionality such as hazard avoidance, compressive sensing, weighted path optimisation.

TesserACT offers functionality for land, marine (streamer/cables/nodes), transition zone, borehole and hybrid (streamer over nodes etc.) projects.

David Ridyard, ACTeQ
Further information at: ACTeQ.net



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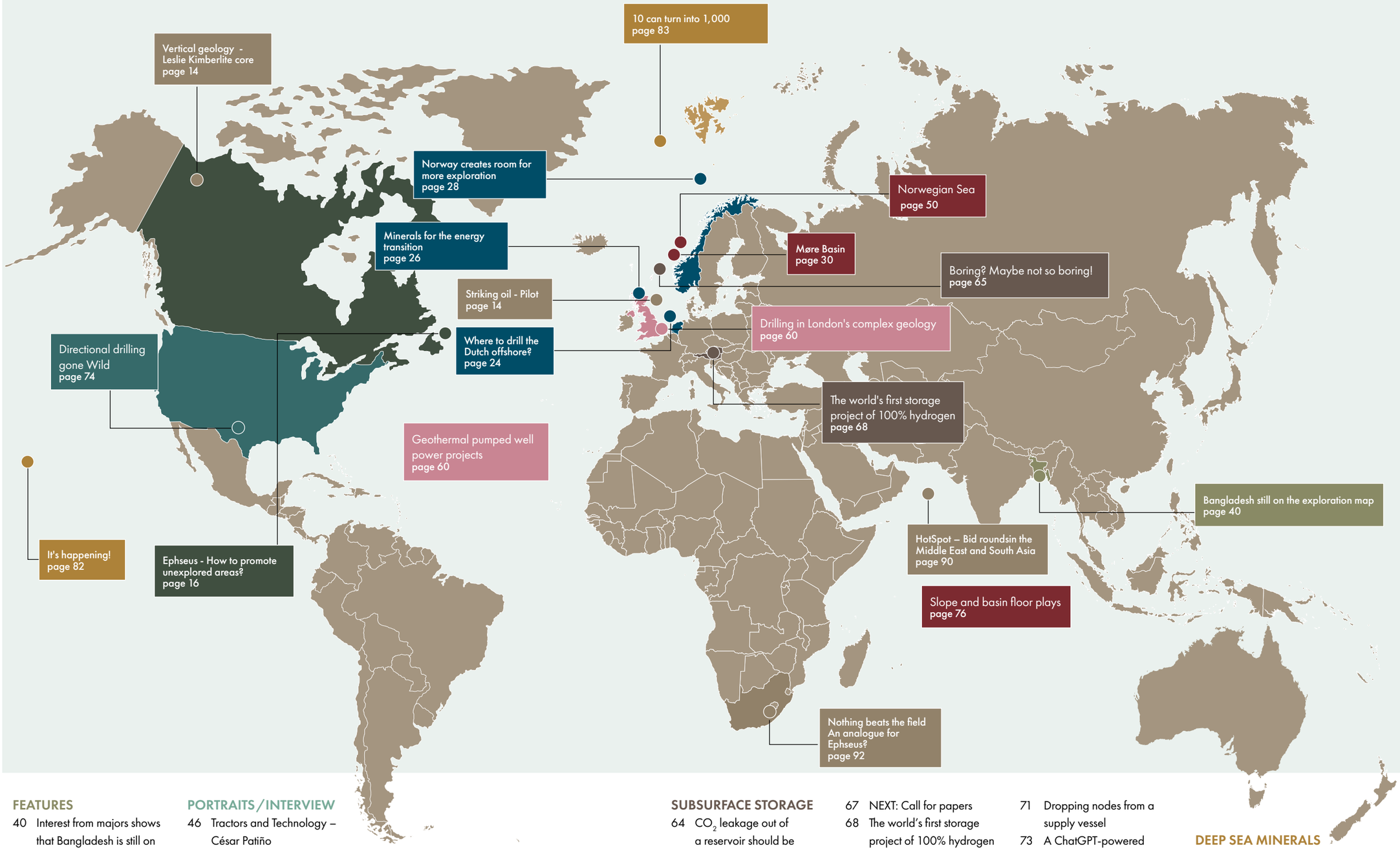


Hotly debated Arctic boundaries

Despite the potential some polar basins hold, ratification of claims is slow because of the realisation that any activity in the area will be extremely challenging.

CANADA IS REPORTED to be the first nation to lay claim to its boundaries extending into the Arctic in 1925. They were followed by the then Soviet Union in 1926. Eight countries subsequently have claimed, including the USA through the state of Alaska, Canada, Denmark through Greenland, Finland, Sweden, Norway, Iceland and Russia. Roughly half the Arctic Circle is bordered by Russia while the other seven claim the remainder.

The Arctic Circle is largely covered by an ice sheet and therefore is governed by the Law of the Sea - a 1982 United Nations treaty. Interestingly, the USA refused to sign the treaty under the Reagan administration and still remains the odd man out of the eight claimants. Under the treaty, if there are disputes that go to tribunals, the law of the seabed is taken into consideration.

Geologists are yet to map the entire geology of the Arctic Ocean seabed with the primary focus being on mapping the bathymetric features such as the ridges.

The territories under dispute in the Arctic are the Northwest Passage, Hans Island, the Beaufort Sea and the Lomonosov Ridge. The USA and Canada are in dispute over the right to control which vessels can enter the Northwest Passage. The same two countries have had a dispute over Beaufort Sea since 2004 and it remains unresolved. The tiny Hans Island is the subject of a dispute between Denmark and Canada. In 2012, it was proposed to divide the island in half, but an agreement was not reached.

> "Oil and gas activity will remain concentrated along the edges of the Arctic Circle and in the Barents and Kara Seas, with exploration of the remainder largely being in the realms of romance and hobbies. "

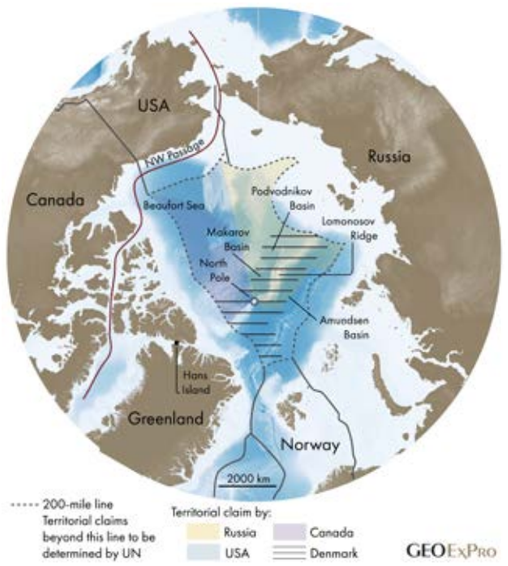
THE MOST SIGNIFICANT DISPUTE

The most significant dispute involves the approximate 1,750 km long but relatively narrow Lomonosov Ridge. This is disputed between Denmark/Greenland, Canada and Russia. Russia's claim is based on it being an extension of the Eurasian Continental Shelf while Canada and Denmark/Greenland propose it is an extension of the North American Continental Shelf. Alongside the Lomonosov Ridge are the Amundsen, Makarov and Podvodnikov Basins. The names of the basins, surrounding features and extent varies per publication.

Whoever eventually succeeds with its claim to the Lomonosov Ridge would inherit a vast area around the North Pole and change the geography of the world significantly. From what is understood, Russia submitted a claim in 2001 to the United Nations Commission and this has since been revised with new evidence to include a larger area. Applications from Canada and Denmark/Greenland have not yet been processed by the Commission and the processing of these applications is thought to be some way off.

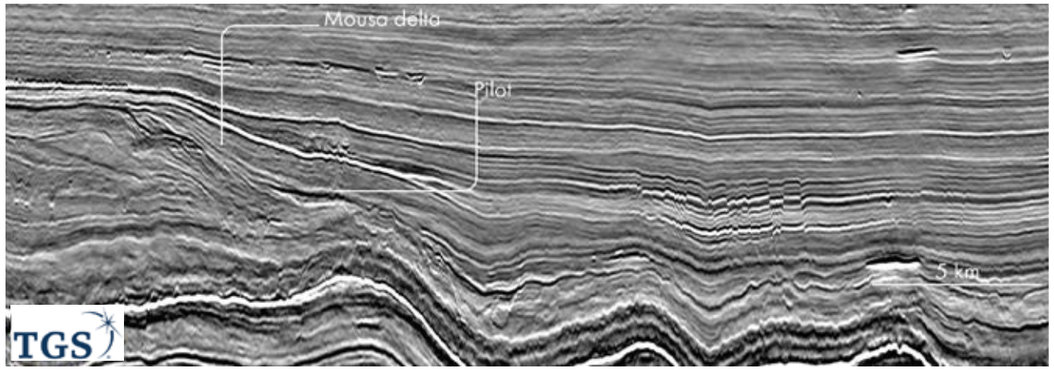
Despite ambitious yet arm-wavy estimates of hydrocarbon resources in the Arctic Ocean, exploration and development is expected to be uneconomic in the foreseeable future. Each of the nations involved in the Lomonosov boundary issue is realistic and understands this. The push for a resolution on the Lomonosov boundary claim is very much political at this stage. Oil and gas activity will remain concentrated along the edges of the Arctic Circle and in the Barents and Kara Seas, with exploration of the remainder largely being in the realms of romance and hobbies. ■

Ian Cross – Moyes & Co



"It's not difficult, it's different"

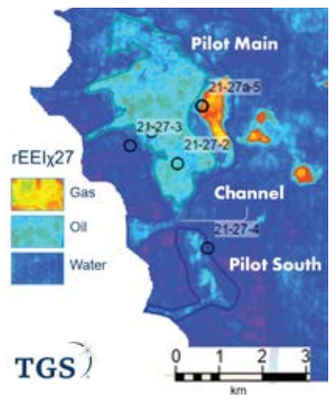
The Pilot heavy oil discovery in Eocene turbidite sands offshore UK is worth a closer look.



Seismic line through the Pilot area, showing the Mousa delta and the lowstand sediments where the Pilot oil was discovered. Can you spot the Blakeney and Feugh discoveries as well?

MANY PEOPLE THINK that heavy oil developments are even worse than lignite, but that is not the case according to Maurice Bamford who recently gave a talk on the Pilot heavy oil discovery in the UKCS.

"Yes, there is more asphalt and petroleum coke in the heavy oil, but it is these ingredients, along with the additional lubricants, that are required for materials needed in the energy transition", Maurice said. Also, based on the current development concept that includes a wind turbine for powering offshore installations and a polymer flood strategy, the project ranks amongst the 5% lowest in terms of emissions of CO_2 per produced barrel. The polymer flooding approach strongly reduces the economic lifetime of the field, which means that the tail end of production, where emissions are usually at their highest, is much shorter.



Map view of the Pilot area showing a seismic inversion for fluid phase.

Pilot is not new, being discovered in 1989 by PetroFina. It has multiple appraisal penetrations and has been subsequently held by a handful of different companies. As such, the current operator Orcadian Energy regards the discovery fully appraised and ready for development given current technology. The estimated volume of recoverable oil is now sitting at around 95 million barrels.

The Pilot reservoir is a relatively extensive amalgamated sand sheet consisting of clean sandstones that were deposited as a lowstand deposit at the foot of the Mousa delta in Eocene times. The seismic section above nicely shows the clinoforms of the delta. However, the architecture of the reservoir is not a simple basin-floor lobe. Depositional patterns suggest powerful erosive turbiditic currents that entered the basin via multiple feeder channels and underwent reflection and refraction within a ponded basin, as Maurice explained during his talk.

THE RESERVOIR THAT IS ALSO A SEAL

The map shows that the main Pilot field is bordered by a smaller oil accumulation, Pilot South. Based on well and seismic data, the identical sands of both fields look to be connected. The only "disruption" is caused by a channel that fed the sands into the sub-basin and beyond, but given that this element also has an oil-filled sand response on the seismic inversion map, it is difficult to explain the 30 m difference in oil-water contact between the two fields.

"Our explanation", said Maurice, "includes a muddy lag on the southern side of the channel." This can be seen on the seismic inversion map as a break between the channel and Pilot South. One possible explanation for this could be contour parallel currents depositing fines on the southern margin of the feeder channel, which subsequently formed a barrier for the migrating oil. "It doesn't have to be a 100% seal, as the oil is heavy and we know there is significant leakage from the widespread paleo-oil column. ■

SEISMIC LINE/MAP: KINDLY PROVIDED BY TGS

COVER STORY

"..there was quite an extensive period of drilling activity in Newfoundland in the 1970's and 1980's, with many of the shallow parts of the shelf tested by the drill bit, but especially the deeper parts were largely undrilled."

Victoria Mitchell - OILCO

COVER STORY

HOW TO PROMOTE UNEXPLORED AREAS?

PHOTOGRAPHY: ERIK MCCLEAN/UNSPLASH

COVER STORY

How to promote unexplored areas?

Insights from Newfoundland and Labrador, Canada, where frontier exploration is now kicking off.

TEXT: HENK KOMBRINK

WHEN IT COMES to finding new oil and gas fields, there's not much that can beat the excitement of frontier exploration. Drilling wells in areas where no one has gone before always results in a lot of speculation and presentation of multiple geological scenarios, while eagerly awaiting the results that may or may not be directly announced.

Companies involved in frontier exploration – especially offshore – are the ones with deep pockets. That's why it is only the majors taking on the risks of going to unprospected places. Within these companies' headquarters, teams are always working towards ranking their global prospect portfolio such that only the most attractive ones will ultimately be drilled.

But let's turn this picture around. How does a country attract a major to drill a frontier well? On a global scale, there are always multiple bid rounds running at the same time, with all these jurisdictions promoting their open acreage with the aim to get as many interested parties as possible. NVenture's Hotspot article in this issue is a prime example of that. Madeleine Slatford shows how only in Asia and the Middle East there are ample opportunities for companies to get a foot in the exploration door across a wide variety of geological settings.

In that light, BP's Ephesus exploration well which was recently spudded in Canadian waters, is a good example to take a further look at. These wells do not pop up all of a sudden. Years of work went into what is now a potential find that may result in the deployment of three to four FPSO's in case the well is successful.

Where to start? Not with BP, but with the Oil and Gas Corporation of Newfoundland and Labrador (Oilco), Canada, whom we caught up with at BEOS in London in April. Geophysicist Victoria Mitchell and Managing Director Jim Keating shared the story on how they have been able to attract majors to their offshore space. Not only through a lot of work and capital spending, but also through having a vision.

MATURE AREAS

"When looking at our offshore area, only a fraction of it is what we call mature in terms of hydrocarbon exploration", says Jim. This is the Jeanne d'Arc Basin, situated around 340 km to the east of Newfoundland. The basin hosts the only four producing fields of the entire shelf and has been explored since the 1980's up to recently.

Apart from the Jeanne d'Arc Basin, most other areas of the enormous continental shelf that measures 200,000 km² remain underexplored until today. "Yes, there was quite an extensive period of drilling activity in the 1970's and 1980's, with many of the shallow parts of the shelf tested by the drill bit, but especially the deeper parts remain largely undrilled until today", adds Victoria.

> "..it was transformational in terms of our ability to map a total of around 700 prospects and leads."

SEISMIC SURVEYS

"So, at some point in the mid 2000's, people in the government asked themselves how to attract interest from the majors," Jim continues. As a vehicle to start promoting the acreage and come up with a strategy of licensing rounds, Oilco was formed in 2007 as a subsidiary of an energy utility company where 97% of the energy stream is based on hydropower. "In a way, we copied the Norsk Hydro model and became a mini-Statoil", Jim adds.

"One of the first things that came to mind was the acquisition of new seismic data", Victoria says. "In 2011, the first 2D survey was acquired by a consortium of PGS and TGS, and using a multi-year strategic and methodical approach in data acquisition, we have been successful in imaging the slope to deep-water along the entire margin.

The acquisition window was limited to the May to September timeframe due to ice and weather optimization. Yet, an extensive grid of 5 by 5 km lines was the result of this project. "But, says Jim, at some point we also realised that companies not only want 2D seismic lines. 3D is what really matters these days. Ideally, this further de-risks areas and shortens the time between licence award and drilling activity.

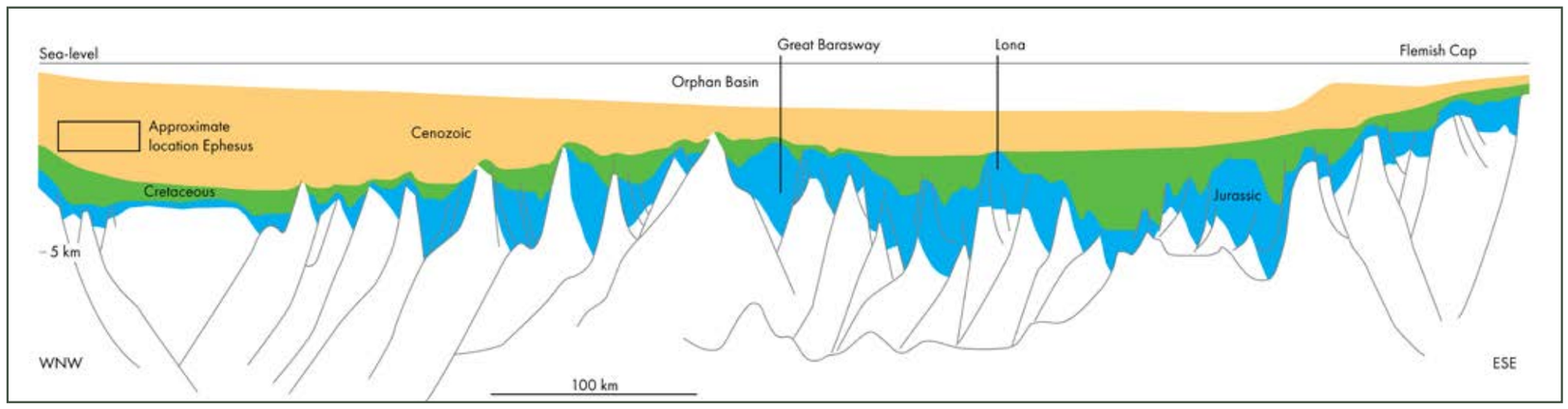
"So, we started also doing that, with the first 3D survey being acquired in 2015. And it was transformational in terms of our ability to map a total of around 700 prospects and leads. It was certainly the trigger for the interest that we were soon to experience, as we identified that about a dozen of our biggest mapped prospects, with reserve potential over a billion barrels each, were sitting in unlicensed areas."

OPEN DOOR POLICY DID NOT WORK

How to handle such a vast amount of seismic data, together with all the studies that had been performed at the same time? Seabed sampling and coring, biostratigraphic analysis and basin studies are just a few of the things that were also extensively worked on.

"The be-all and end-all is that we concluded that just relying on an open-door policy was not going to work", Jim says. "There is just too much for companies to absorb and we decided that we needed to present the areas in a much more manageable way for exploration teams to handle. As a result, we shared our ideas with government and the regulator and soon, The Canada-Newfoundland Offshore Petroleum Board moved to a scheduled land tenure system where smaller parts of the margin are offered as part of consecutive licensing rounds." ▸

CROSS-SECTION REDRAWN AFTER CAWOOD ET AL. (2021)



WNW-ESE trending cross-section through the Orphan Basin, illustrating the Jurassic and Cretaceous syn-rift succession and Cenozoic post-rift interval. The Ephesus well is situated towards the western margin of the basin and targets an Eocene submarine sandstone reservoir.

DIFFERENT TIMES

"Let's face it, oil is not a popular word these days", Jim continues. "And while equity participation in offshore oil developments has delivered significant returns so far to the state, it also entails significant risks and continued investment levels that a small province may not be well suited for." Whether or not the provincial Newfoundland and Labrador government wants to continue to have an active stake in oil and gas developments is something that is currently debated," Jim concludes.

"It's uncertain times in that respect for OilCo, but we are tremendously proud of what we have done the past 15 years in creating value and investment for the province. We are now entering an important and possibly final chapter of our story where these most interesting prospects identified nearly a decade ago are being drilled. It's exciting times ahead when it comes to the two drilling campaigns that will unfold this summer."

And it worked. Exxon was the first to bite in 2015. "It felt as a proof of concept for us", adds Jim. "The availability of 2D and 3D seismic has been instrumental in successful land sales even in times of low commodity prices. Since 2015, the region has garnered over $4 billion in work commitments from exploration companies."

"It felt as a proof of concept for us."

By 2018, up to 14 companies had made bids for acreage, with over half being new entrants to the region. Because the licensing term is six years with a possible extension to nine years, and companies tend to wait and see what their neighbours are doing, the drilling rigs did not pour in right from the license awards. "That's the phase we are at now, following some licence extensions a couple of years ago", Jim says. "And yes, there were some uncertainties around offshore regulations that had to be ironed out too", he adds.

But, here we are in 2023, and there is the possibility of more than just the Ephesus well being drilled. An Exxon-led group will namely spud the Gale well in the Jeanne d'Arc basin north of the Hebron and Hibernia platforms.

THE EPHESUS PROSPECT

The Ephesus prospect – or Cape Freels as it is called by Oilco - lies in the western part of the Orphan Basin. This basin finds its origin in the Middle Jurassic to mid-Cretaceous rifting event that is associated with the first stage of Atlantic continental spreading. The oldest rocks in the basin are therefore thought to be of Middle Jurassic age, overlying metamorphic Paleozoic rocks. Sedimentation continued more or less uninterruptedly until present-day, apart from a Maastrtichtian-Danian phase of erosion.

The main reason why the western part of the Orphan Bain appeared on the exploration radar was the identification of satellite slick anomalies in 2010. This prompted the acquisition of 2D seismic lines in 2012. Interpretation of these lines then suggested the presence of a Paleocene-Eocene play, which subsequently triggered the acquisition of a long-offset 3D survey in 2015. The long-offset nature of the seismic proved of key importance, because it is only in the far offset lines that the prospect is properly imaged.

The Ephesus prospect lies in the Cenozoic post-rift sedimentary interval that drapes the syn-rift Jurassic to Lower Cretaceous stratigraphy. The reservoir likely consists of Eocene submarine fans, shed off the continent into the Orphan Basin.

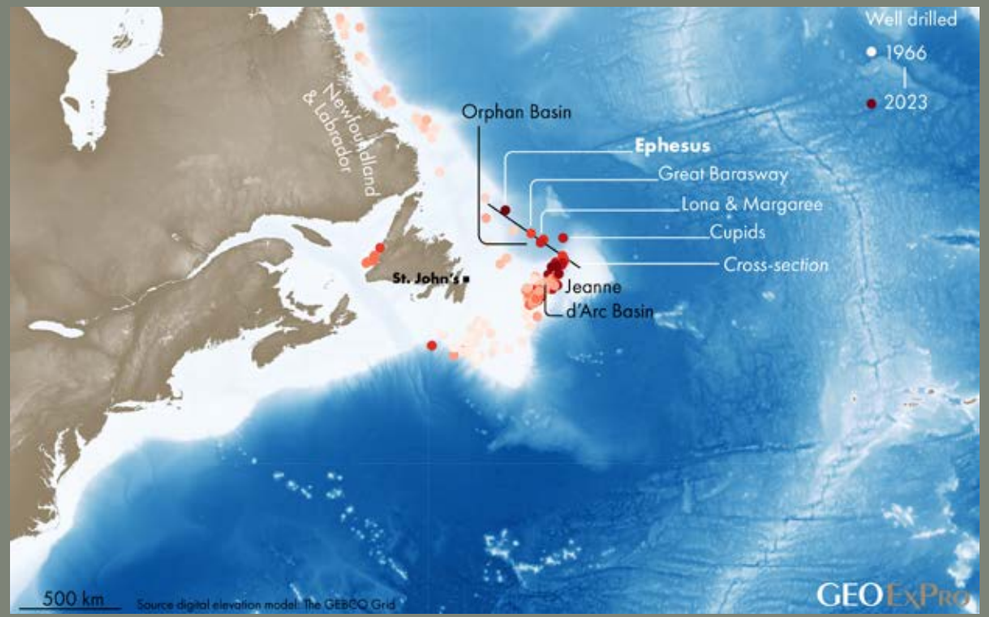
According to a geologist who worked in the area extensively, there are good indications for fluid migration below the prospect, as the escape features illustrate on the seismic line. However, the nature of these fluids is less well-known, and there could be a chance that Ephesus contains gas rather than the more desirable oil. Another factor that was described by the geologist as fairly risky is the source rock. The area relies on a Cretaceous source rock that has not been encountered in many wells and is therefore poorly known. Only a few old well reports made a mention of a possible source rock and the data presented were not particularly consistent. On that basis, Ephesus can surely be categorised as a frontier exploration well, with a huge upside but equally with quite some risks associated with it too. ■

THIS IS WHY EPHESUS IS A WELL TO WATCH

Looking at the first year exploration wells were drilled along the Newfoundland and Labrador shelf, it is clear how much of a frontier well Ephesus is.

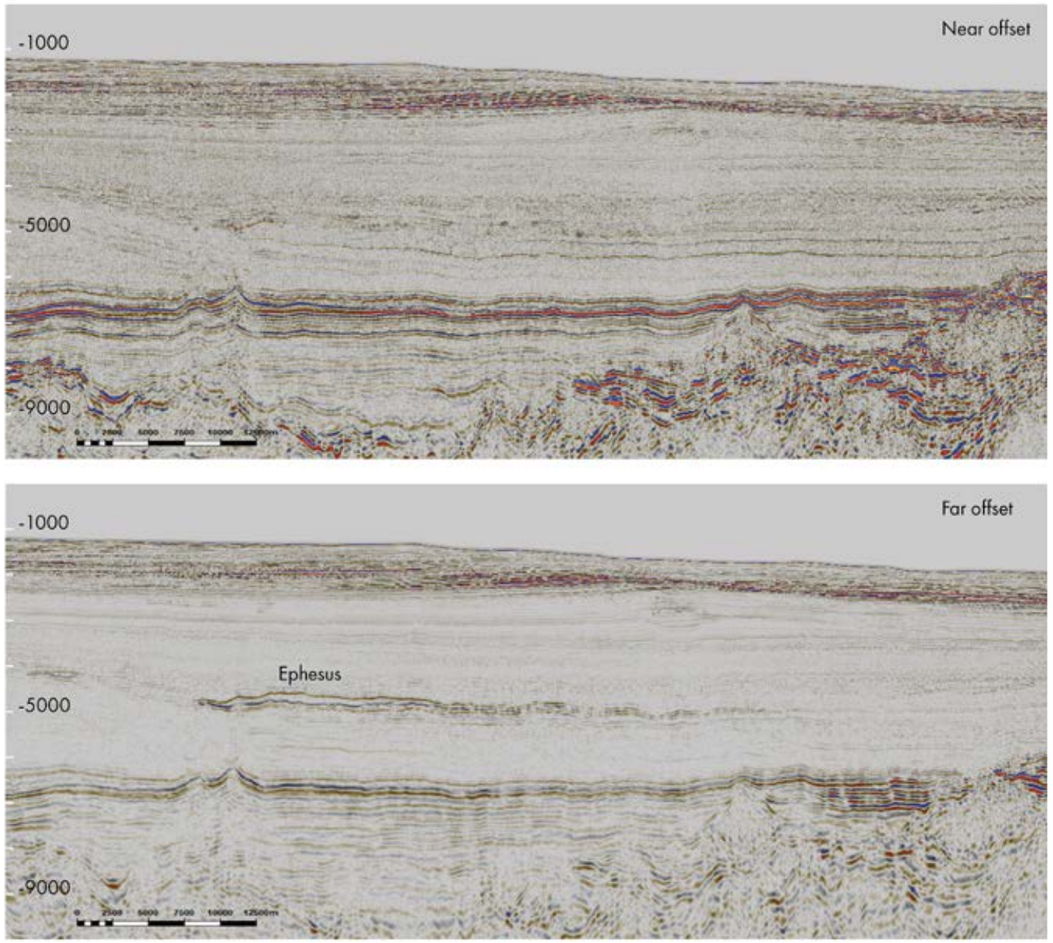
We plotted the exploration wells drilled on the Newfoundland and Labrador shelf on a bathymetric map and colour-coded the wells to the year they were completed. A nice picture emerges as a result. First of all, it is clear that early exploration focussed on the shelf areas only. But, despite being limited by water depth, the geographical distribution of wells is quite impressive. Then, from about the mid-1980's, a geographical concentration of drilling takes place into the area of the Jeanne d'Arc Basin, where the only currently producing assets are located.

Chevron is the first company that moves to deeper water in 2007 through drilling Great Barasway, followed by Lona (Chevron) in 2010, Margaree (Chevron) in 2013 and Cupids (Equinor) in 2015. But now, BP will move even further away from the Jeanne d'Arc Basin, with Ephesus being even further to the northwest in around 1,300 m of water, testing an Eocene deep-water sandstone target.



Map showing the location of the Ephesus well off Newfoundland, together with the other wells drilled across the shelf over time. The colour-coding is according to the year each well was completed, nicely illustrating how early exploration focused on shallow-water areas only.

WELL DATA: CNLOPB.HUB.ARCGIS.COM



SEISMIC LINES KINDLY PROVIDED BY OILCO

Seismic lines through the Ephesus area, illustrating how the far offset clearly brings out the prospect through its higher amplitudes.

NORTHWEST EUROPE

"I am touched and excited with this government..."

Anders Wittemann, Wittemann E&P Consulting

Where to drill in the Dutch offshore?

Following the release of an online exploration tool last year, we put it to use and created an overview of the most prospective areas for each petroleum play.

THE GEODE PLATFORM, an online viewer and database that was compiled by EBN and TNO – Geological Survey of the Netherlands - provides an overview of the exploration potential and exploration risks associated with the main petroleum plays in the Dutch offshore. This was done by mapping reservoir presence, reservoir effectiveness, seal presence and charge and migration for each of the plays and combining these into composite common risk segments.

For each of the nine plays available in the tool, ranging from the Cenozoic shallow gas play to the Carboniferous, we selected and briefly described one area that holds significant potential when it comes to finding oil or gas. By no means this overview is exhaustive, it is nothing more than the result of a browse through the various play maps available in GEODE. Rather, it forms a starting point for further discussion on prospectivity and illustrates where future drilling could take place. If it will take place. ■

MORE INFORMATION AT: WWW.GEODEATLAS.NL

AN UPTICK IN EXPLORATION YET?

The release of the GEODE platform has not yet resulted in an uptick in exploration activity in the Dutch sector, even when there seemed to be an increase in awareness that domestically-produced gas is preferred over imported gas. So far this year, not a single exploration well was drilled offshore.

Maybe it is not too much of a surprise, given that ONE-Dyas, the operator of the N05-A development, saw their project grinding to a halt recently as a result of yet another appeal related to nitrogen deposition during the platform and pipeline construction phase. The same already happened to the flagship offshore CCS project Porthos. The fact that the N05-A development is probably the cleanest when it comes to operating emissions was not important. The platform is to be fully electrified, powered by a wind farm in German waters.

It must have put another damper on the future of the Dutch offshore oil and gas sector. A future that was always going to be a short one, given the very modest reserves left in the existing fields and the limited exploration potential in the light of the many wells already drilled (~1,000).

Upper Cretaceous Chalk - gas
Carboniferous-sourced gas migrating up from more deeply buried strata towards the north may have charged the Upper Cretaceous Chalk that is directly overlying the Carboniferous in this area of the London-Brabant Massif (LBM).

Lower Cretaceous - Holland oil
Close to the beaches of The Hague, further exploration of the erratic and difficult to map Holland greenstone might result in the odd surprise.

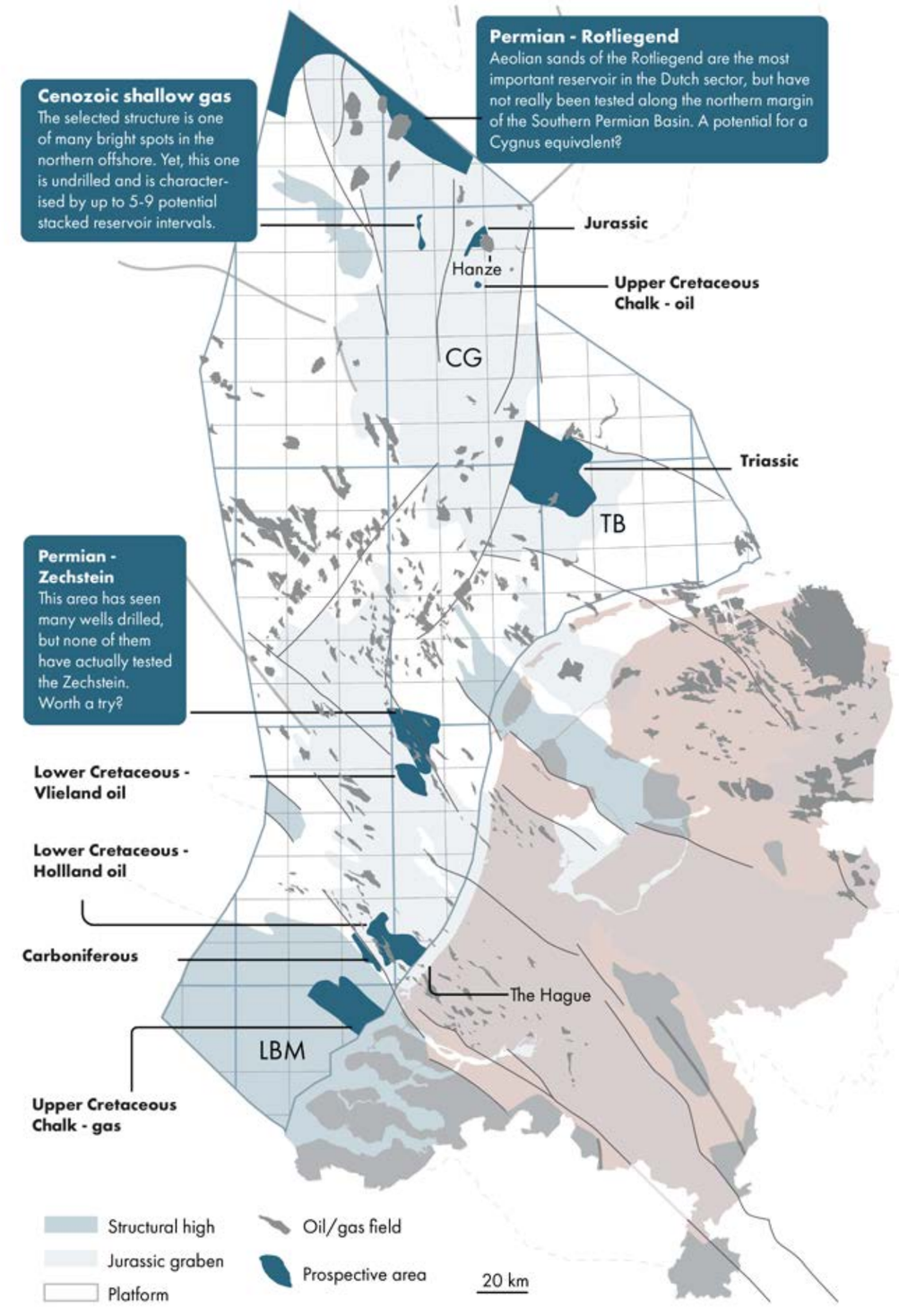
Triassic
The Triassic is the most difficult play to find the most prospective area for. It is present across most parts of the offshore. This part of the Terschelling Basin (TB) has the lowest density of wells drilled and may therefore warrant another look.

Upper Cretaceous Chalk - oil
The Central Graben (CG) has got few structures left to drill when it comes to the Chalk, but this little area looks promising for the Chalk play in terms of reservoir, charge and seal!

Lower Cretaceous - Vlieland oil
Even though there are Vlieland sandstone oil fields just to the north, this area remains mostly undrilled. Why? Maybe a lack of decent structures? Or a migration shadow, which is considered the highest risk here. Yet, the play fairway mapping exercise suggests this area to be promising indeed.

Jurassic
Close to the producing Hanze field (Chalk), this area promises to be quite prospective in the Jurassic interval. Is there potential for a step-out well from the Hanze facility?

Carboniferous
There are sandstones, sources and seals aplenty in the Carboniferous, and it can be found almost everywhere across the offshore, but this area along the southern margin of the West Netherlands Basin looks the most promising of all.



Can Aberdeen become a center for minerals needed for the energy transition?

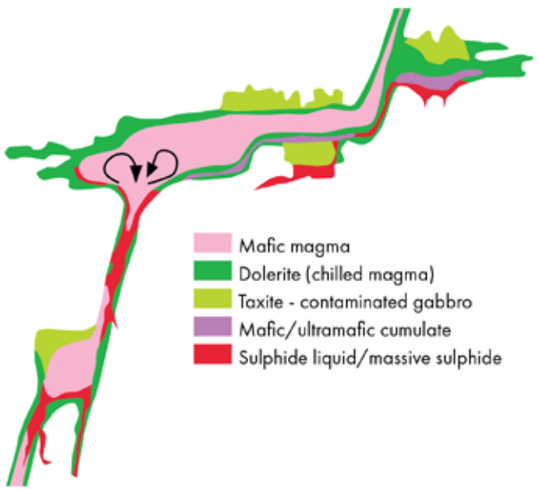
Drilling and prospecting for copper-nickel sulphide deposits is ongoing in an area that is currently still the oil capital of Europe.

ON A RAINY DAY IN MARCH, on a quiet countryside road north of the village of Ellon in Aberdeenshire, northeast Scotland, I am welcomed by geologist Drew Craig from Aberdeen Minerals. We are to visit the site where his company is drilling a number of exploratory boreholes to sample a mineral deposit that may host economic quantities of nickel and copper.

This place has been on the radar of the mining industry for a while. "Ever since a local farmer spotted that his crop of turnips – a Scottish delicacy – experienced suboptimal growing conditions and had some ground samples tested, it has been known that anomalous concentrations of nickel are the root cause of the issue", Drew says.

The companies that initially came to the area following the discovery of metals close to surface also had core samples taken. However, the quality of the material and the reliability of the analyses has prompted Aberdeen Minerals to embark on a new drilling campaign. "The reporting standards for mineral deposits are very strict and to move a site up the ladder from a prospective deposit to a commercially viable mine one needs to comply with very stringent rules of reporting and sampling", Craig explained later during the visit.

Muddy conditions during drilling of one of the boreholes for Aberdeen Minerals north of Ellon, Scotland.



Schematic illustration of the process of enrichment in a magma chamber where a sudden velocity drop results in the settling of sulphides.

In contrast to oil and gas wells, the boreholes drilled here have a 45 degrees angle from the start. It is done to ensure maximum exposure to the Ordovician dyke that dips in an opposite direction.

Previous models of the mineral deposits in the area assumed that they had formed as a result of gravitational settling of sulphide deposits within layered intrusions into the Dalradian host rocks. The current model favoured by Aberdeen Minerals is one of a conduit-style magmatic sulphide, as the figure here further illustrates. One of the mechanisms through which enrichment in sulphides takes place is the settling of these minerals when a magma reaches a larger space where it loses momentum.

Apart from the area north of Ellon, the company has also carried out airborne surveys to map larger areas of northeast Scotland for the presence of other magmatic bodies. It is an interesting thought that the oil industry settled down in an area characteristic of its granites, gneiss and intrusions. Will the geology of Aberdeen become key to its future again, similar to the times when the city was a major exporter of granite? ■

PHOTOGRAPHY: HENK KOMBRINK; CROSS-SECTION: REDRAWN AFTER BARNES ET AL. (2018)

Norway creates room for more exploration, but it won't get a thank you from Europe

With additional blocks up for grabs in the Barents and Norwegian seas and discussions about a pipeline to the far north it is clear that Norway is aiming at finding and producing more oil and gas.

"I AM TOUCHED AND EXCITED with this government", wrote E&P analyst Anders Wittemann on LinkedIn. He referred to the announcement of the 2023 APA Round – Awards in Predefined Areas – whereby 92 additional blocks were opened up for applications, mainly in the western part of the Barents Sea. Wittemann does not often express himself on social media this way, so this is telling.

Sidsel Lindsø from ExploCrowd shared Wittemann's enthusiasm: "I have not seen more political heavyweight than this before, at least in my career", she writes in her LI post. "All the proposed block additions have been granted and the announcement was made weeks earlier than usual." With the deadline for applications closing late August instead of mid-September, there is another sign that Norway is making serious efforts to explore and produce more, quickly.

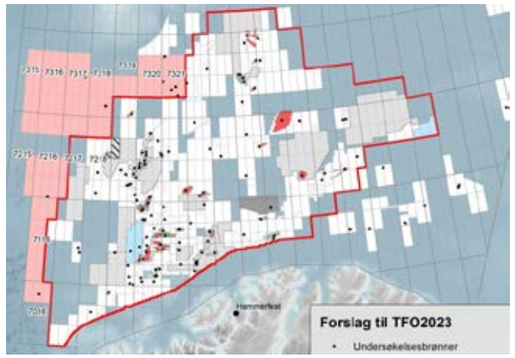
This is a fascinating development. Norway, the only country in Northwest Europe that has significant reserves left, added to remaining exploration potential, also happens to be the only country in this part of the world where the continuation of the oil and gas industry receives such widespread support from the government.

Imagine a country like Germany announcing a bid round of this kind; even in today's world that would be hard to imagine. Instead, Olaf Scholz visited several geothermal projects in the last couple of weeks, reflecting on which way Germany wants to go. But, even when going big on geothermal, he will also be very pleased to hear that Norway does whatever it can to support the demand for gas from Europe and Germany in particular.

NO THANK YOU

But Norway will most likely not be openly thanked for this from Brussels. A person from Offshore Norway told me in November last year that he only manages to meet people from the European Community in public places such as bars and hotels, where one does not need to sign a register that shows one's affiliation. Receiving oil and gas representatives from Norway is clearly not fashionable these days.

At the same time, I was told that Norway welcomed many delegations from the continent in the weeks after the invasion of Ukraine by Russia, informing themselves on the possibilities to extend contracts and up production. But again, all under the radar.



This map shows in pink the blocks that were proposed to be part of the upcoming 2023 APA Round, clearly extending acreage in the west of the Barents Sea. All these blocks have now been included in this year's round, as the NPD confirmed in May.

Will Norway be unhappy not to be publicly thanked for their efforts to supply more gas for longer? I don't think so. Norwegians are not the most emotional people after all. In the meantime, it will be jolly good for their state pension fund. ■

Further information at: npd.no

A BARENTS SEA PIPELINE?

Is it a surprise that the discussion around increasing the gas export capacity from the Barents Sea has recently seen a revival? For long, the big question for the Barents Sea has been and continues to be: "Do we build a pipeline such that companies will start exploring more or do we wait for these discoveries to be made first before deciding on building a pipeline?"

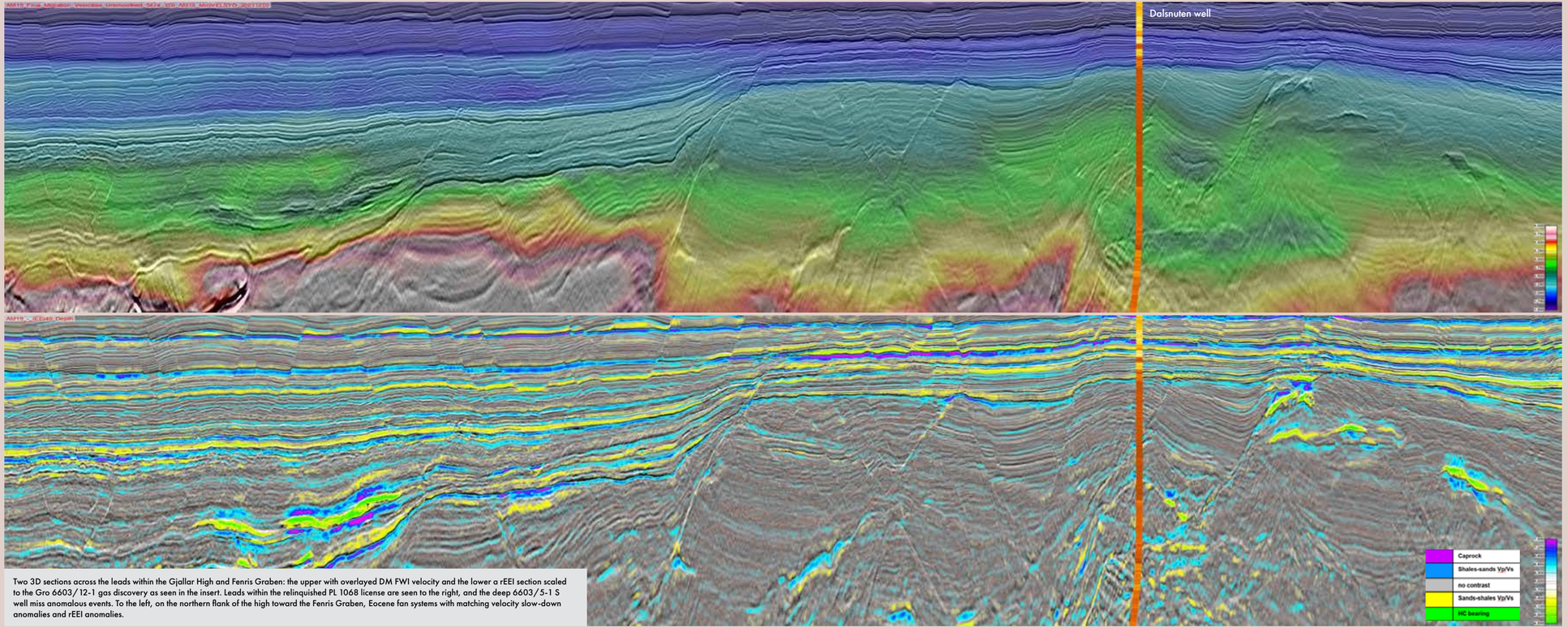
Clearly, the latter dominated the discourse for a long time, further supported by the lack of commercial exploration success in recent years and the exit of some players from the basin.

However, the new energy situation in Europe has turned this view significantly. In April, Reuters reported that the Norwegian gas infrastructure operator Gassco suggested that building a pipeline from the Barents Sea would be worth examining again. Recent exploration success must also have added more gravitas to this.

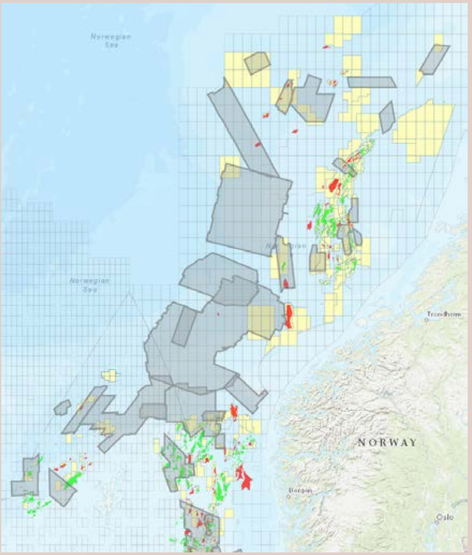
SOURCE: NPD

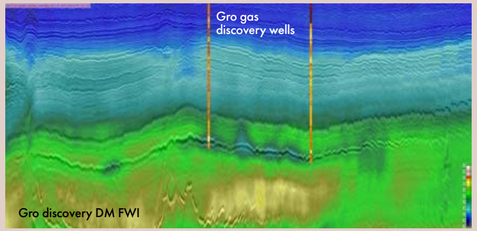
Dynamic Matching FWI + rEEI makes a difference to your interpretation

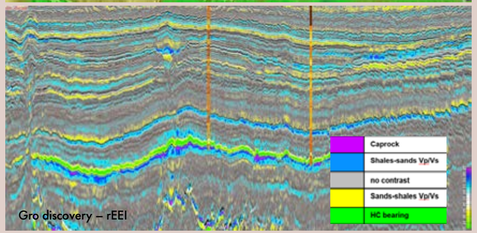
The westernmost deep-water areas of the Norwegian Sea have been explored for about 30 years. Early gas discoveries like Ormen Lange and Aasta Hansteen motivated optimism, followed by the "elephant, dome drilling period" with few successes, like Helland Hansen, Vema, Fles, Naglfar, Gjallar North and South. Thus, besides these few small gas discoveries, the potential of the deep-water Norwegian Sea still needs to be unlocked. Some answers lie in a better 3D seismic database with new tools like DM FWI's detailed velocity volumes and better AVO screening tools like rEEI, as shown in this article and seismic foldout.



Two 3D sections across the leads within the Gjallar High and Fenris Graben: the upper with overlayed DM FWI velocity and the lower a rEEI section scaled to the Gro 6603/12-1 gas discovery as seen in the insert. Leads within the relinquished PL 1068 license are seen to the right, and the deep 6603/5-1 S well miss anomalous events. To the left, on the northern flank of the high toward the Fenris Graben, Eocene fan systems with matching velocity slow-down anomalies and rEEI anomalies.







Gas to Europe: Refocusing exploration efforts in the Atlantic Margins

BENT KJØLHAMAR, ADRIANA CITLALI RAMÍREZ AND REIDUN MYKLEBUST, TGS

According to the World Economic Forum, Europe has enough gas for the first quarter of 2023. However, there is no time to sit back, as the remainder of the year could bring new gas shortages and competition for global suppliers' resources will likely intensify as summer draws to a close.

The LNG demands from China and India could also increase, while the supply from Russia could reduce further or even cease completely. The outcome would be a larger mismatch between Europe's needs and the global suppliers' ability to fulfill those needs and/or their willingness based on competition for energy security.

To our knowledge, there are no basins as close to a major energy market on the planet and yet poorly explored at the same time as the Møre Basin. There are two exemptions: the massive Ormen Lange field and the Aasta Hansteen field which produce gas from the northern part of the Vøring Basin.

Aasta Hansteen came on stream in 2018 and it is predicted to come off plateau production this year and be shut down in 2027 if no new discoveries are tied-back to its infrastructure. As such, the Polarled pipeline and the existing infrastructure in the area are in danger of becoming a liability, while there are stranded gas discoveries toward the west.

Against this backdrop, with an expected increase in demand for LNG in Europe, it is pivotal to find and develop more gas to fill the Polarled pipeline. Can the Atlantic Margin come to the rescue?

In this article, we sum up what is new on the Atlantic Margin, especially how we use high-end seismic imaging and model building with dynamic-matching full waveform inversion (DM FWI) to interpret the geology and gas anomalies, alongside observations underpinning why the volcanic rocks and hydrothermal vents stimulate gas migration into traps created by the same volcanic rocks.

New data and technology are revealing secrets in a formerly elusive deep-water basin explored for more than 25 years. We may soon have the answer if indeed the gas itself is generated from the heat when volcanic sills intruded organic-rich Cretaceous shales. We hope this article inspires you to do more frontier exploration in the middle of Europe!

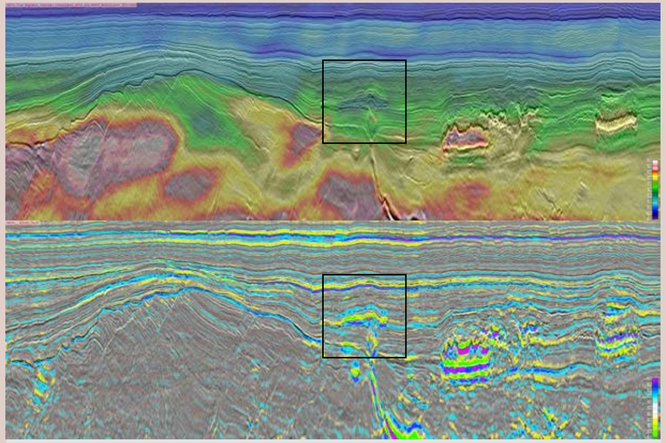


Figure 1: The top line shows AM19 PSDM data with DM FWI velocity overlayed. Notice the sharp velocity slow-down anomaly (inserted rectangle) within the hydrothermal vent structure, possibly sourced from a Cretaceous hosted sill intrusion below. Below, a line from the rEEI volume shows a class 3 AVO anomaly matching the slow velocity anomaly, similar to the one observed in the proven Gro gas field. The lead is one of many found in both flanks of the Gjallar ridge to the left.

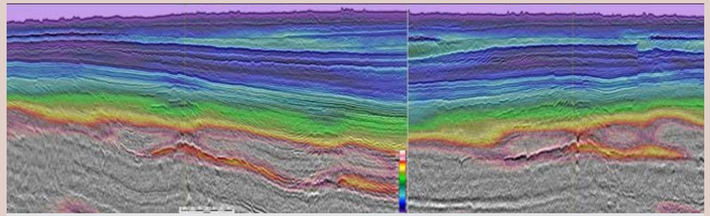


Figure 2: The crossing 3D lines in AM20 survey in Northern Møre Basin are displayed with DM_FWI velocities overlayed. Two sand prone Cretaceous formations, Nise and Lysing can be observed, with the latter displaying slower velocities than above and below in red/yellow. Above, at the tie-pioint, the Nise formation has a strong soft top and a subtle slow velocity anomaly in blue-green. In the top section mud diapirs with sharp velocity anomalies are seen.

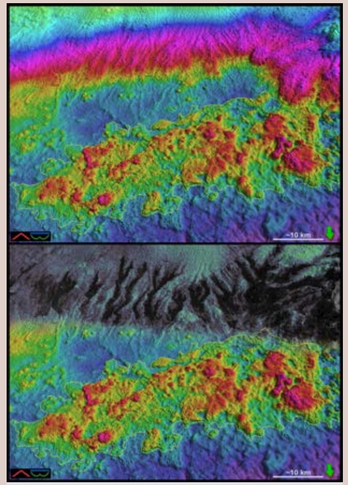


Figure 3: The deep Møre Basin, north from the Tampen Spur, Manet High and Margarita Spur, has barely any explorations wells. The East Shetland platform has produced Paleogene sands in the North Sea and Faroe-Shetland Basin. The top map shows the Top Balder/Tare (Eocene) structure. The lower map shows the thickness of the top of Balder formation. Deep erosional incisions are seen (dark). Potentially Paleogene sand have passed into the Møre Basin too. In front of the erosional incisions is the newly described, Jolnir Dome, a 1200 sqkm closure, awaiting its first exploration well.

WHAT HAS HAPPENED IN THE NORWEGIAN SEA IN THE LAST FIVE YEARS?

TGS, in collaboration with VBER and key clients, has worked to uncover new play models along the Atlantic Margin within the Norwegian Sea through combining research, latest subsalt technology and geological insight. In addition, during the past five years, TGS acquired approximately 59,000 sq km of modern, dense 3D streamer data (about 1,4 times the area of Denmark), thereby creating a consistent regional coverage. The surveys were processed in depth with the latest PSDM technology utilising DM FWI velocities. This has resulted in a new indicative tool where distinct slow velocity anomalies indicate existence of a gas column and reservoir quality. The extensive technical interpretation done by VBER and TGS reveals details about *undiscovered* intra-basin highs within the oil window, illustrating how immature these areas are.

NEW TOOLS IN THE TOOLBOX

The AM19 DM FWI velocity field overlaying the PSDM stack bears interpretable details as displayed in Figure 1. The relative Extended Elastic Impedance (rEEI) volume on the right, where the gradients are extrapolated to about 45 degrees, shows robust AVO attributes. In this rEEI volume, shales and source rocks can easily be differentiated from water or gas-filled reservoirs.

Using both structurally confined DM FWI slow velocity anomalies with class 3 rEEI AVO anomalies, matched and scaled as the proven Gro gas discovery (Foldout), in analogous terrain and depth, yield strong indications of new gas.

Screening in this manner, we confirmed already defined leads within the now relinquished PL 1068 area on the top of the Gjallar Ridge plus more than ten structurally and stratified defined leads of various sizes. Based on the anomalous gross rock volumes surrounding Gjallar Ridge within tie back distance, our conclusion is that the total lead volumes present should be enough for a standalone development.

HIGHER-RESOLUTION IMAGING OF THE GEOLOGY

Better seismic velocities unveil new details within flood basalts and new migration algorithms like RTM, the sub-basalt terrain. The DM FWI velocities are key to understanding the volcanic facies. Occasionally structurally confined slowness anomalies down below 3km/s sit between fast or hard layers up to 6km/s. These slow patches are interpreted as interbedded sandy sediments (potentially gas-filled), ultra-porous vesicular basalts or mud rocks.

After that, there is a sharp drop in sub-basalt velocities. In the northwestern Vøring Basin, we interpret a thick Cretaceous basin below basalts. In the northern Møre Basin (AM20) we see a thinner 2-400 m slow sub-basalt layer before a rifted terrain with very high velocities indicating an old, pre-Cretaceous or even pre-Mesozoic rifting phase. Common for both places is that the slowest velocities (~2500 km/s) sit at the crest of the sub-basalt structures.

WHAT'S NEXT?

There are enormous sub-basalt closures all along the Atlantic Margin, with significant catchment areas for migrating pre-Paleogene hydrocarbons. In addition, the likely pre-Cretaceous highs are located within the oil window. In support of this, a seafloor sampling cruise detected strong oil seeps above the sill intruded inner flows in the northern Vøring Basin. One of these sub-basalt targets is a candidate to be drilled. We are eagerly awaiting an announcement and new activity in this potentially highly prolific margin. ■

Data operations as a service

If oil and gas companies were polled and asked to rank on a scale of 1 to 10 how quickly they get access to priority data requests or how timely they are fulfilling high-priority data deliveries to third parties, be it partners, offset block operators or governments, most would rank at the lower end of the scale.

FEMI MAKANJUOLA, DIRECTOR AT KATALYST, US OPERATIONS

PHOTOGRAPHY: KATALYST

Data delivery challenges are attributed to rigid internal workflows or processes and a need for more capacity/legacy media infrastructure to handle data volume and data delivery media variability. Data vendors could have recorded data on legacy tape media (9-track, 21-track, 3480s, etc.), more modern media (3592, LTO, etc.), or electronic (public cloud, FTP, etc.). These inefficiencies lead to high delivery turnaround times for priority data requests which delay access to data impacting timely business analysis and critical business decisions.

COST PROHIBITIVE

Oil and gas companies receive business-critical data from different sources, including acquisition vendors, reprocessing vendors, multi-client vendors, or previously acquired data stored at a physical storage company. These data sets are delivered via legacy tape, modern media, and paper or electronically via FTP or cloud service providers. Once the data is provided, data technicians establish a chain of custody, log high-level metadata in the document management system, and forward the media to the appropriate group that reads or extracts data from the media. ▸

Depending on the volume, number of tapes, and media type the data is delivered on, the capability of oil and gas companies to expeditiously provide workstation-ready data to the end users is limited in most cases. This is because of the infrastructure and maintenance requirements (tape drives, servers) and the technical expertise needed to maintain a complex environment.

It is cost prohibitive for oil and gas companies to manage the variability and complexity of maintaining a multifaceted large-scale digitalization environment. Companies may have an obligation to provide these datasets to third-party recipients such as partners, offset block operators, buyers of an asset, or government agencies. These "data operations" challenges described above lengthen the delivery turnaround time of priority data requests.

REDUCING THE DELIVERY TURNAROUND TIME

Data Operations is a service offering focused on securely disseminating priority subsurface data to internal end users, external recipients such as partners or governments, and platforms supporting business operations and decision-making. Oil and gas companies can reduce the delivery turnaround time of high-priority datasets by outsourcing data operations services to companies with the technical expertise and the infrastructure to fulfill data delivery requirements. Benefits of outsourcing data operations include reallocation of resources to other value-added activities, reduced infrastructure and maintenance burden, and streamlined processes.

OUTSOURCING OPERATIONS

Companies are dissatisfied with the high turnaround times of priority data requests. These higher delivery times are due to rigid and stringent internal processes, a lack of capacity and infrastructure to manage and handle the volume, and media variability that delays critical business analysis and, ultimately, critical business decisions. Companies can reduce the high turnaround times by outsourcing data operations services. ■

PHOTOGRAPHY: KATALYST

FEATURES

"..it is too little and it is getting too late. More needs to be done, and soon."

Hemmo Abels - Delft University of Technology

INTEREST FROM MAJORS SHOWS THAT BANGLADESH IS STILL ON THE EXPLORATION MAP

It is too early to conclude that there is nothing left to find in Bangladesh, despite declining production figures. Proposed changes in Production Sharing Contracts form an important factor in stimulating exploration offshore.

THOMAS DAVIS, VENTURA, CA, AND BADRUL IMAM, UNIVERSITY OF DHAKA

GAS is the dominant energy source for power generation in Bangladesh; it has fueled the nation's rapid economic growth during the last several decades. However, dwindling domestic production, mostly from fields discovered before 2000, and growing LNG imports are making the nation more energy dependent on external events.

The exceptional LNG price spike from the Russia-Ukraine war and the government's three-quarter-year pause on spot market purchases are a testament to that.

Increased gas exploration in resource-rich Bangladesh would alleviate its energy concerns and avoid economic contraction. Although the spot price of LNG is now considerably lower than in the recent past, concerns remain about future spikes, a gradual and sustained price increase over time, and the reliability of external supplies.

Bangladesh, a country close to the water line.

PHOTOGRAPHY: TAREK SUMAN/UNSPLASH

46 NEW WELLS

In a 2021 GEO EXPRO article, we already advocated for increased gas exploration of the many opportunities in Bangladesh. If anything, the market and supply experience of the last two years has strengthened that position.

Here, we focus on offshore exploration and recent government moves to increase exploration countrywide. Petrobangla has announced plans to drill 46 wells in the next two years: 17 exploration wells, 12 development, and 17 work-over wells, with five exploration wells to be drilled in 2023 and 12 in 2024. In contrast, the last two decades only saw one to two exploration wells drilled per year.

At the same time, accompanying commercial enticements and planned bid rounds should increase exploration interest from international oil and gas companies (IOC), with Petrobangla's proposed changes to the offshore Production Sharing Contracts (PSC) awaiting approval by the relevant authorities.

Changes include natural gas pricing tied to 10% of Brent Crude Oil, e.g., Brent at $80 USD/barrel will result in gas priced at $8.00/MCF. Petrobangla also proposed to reduce its take of "profit gas" to a mean of 55% from 67.5%. In addition, IOCs with future offshore discoveries can export gas when production exceeds domestic demand.

And finally, Bangladesh resolved its maritime boundaries in the Bay of Bengal with India and Myanmar by 2014, resulting in the offshore sector having an Exclusive Economic Zone that is nearly double that of the nation's onshore area.

A LARGE UNDER-EXPLORED DELTA

A significant part of the offshore Bangladesh sector is occupied by the under-explored Ganges-Brahmaputra delta, the largest delta in the world. Productive oil and gas basins lie in adjacent offshore India and Myanmar: the Krishna-Godayari and Mahanadi, and Rakhine Basins, respectively, with large recent gas discoveries made in the adjacent Myanmar offshore sector.

However, compared to its neighbours, the offshore sector of Bangladesh is poorly-explored: only 21 shallow-water and no deep-water wells.

The planned offshore bid round has 26 blocks: 11 shallow water and 15 deep water blocks (> 200 m depth, Figure 1). A 2001 Petrobangla/USGS (United States Geological Survey) Natural Gas Assessment estimated the undiscovered, conventional resources in the shallow-water Bangladesh sector at 8.8 TCF (mean) with a range of (2.4 - 17.4 TCF). The shallow-water zone has two gas fields; the undeveloped Kutubdia discovery (1977) estimated at 780 BCF, and Sangu that produced 488 BCF (produced from 1996 to 2013).

Geological data indicate that the offshore has significant remaining natural gas resources, further de-risked by major oil and gas discoveries in adjacent waters in Myanmar and India.

Several stratigraphic plays and trap opportunities are known to exist:

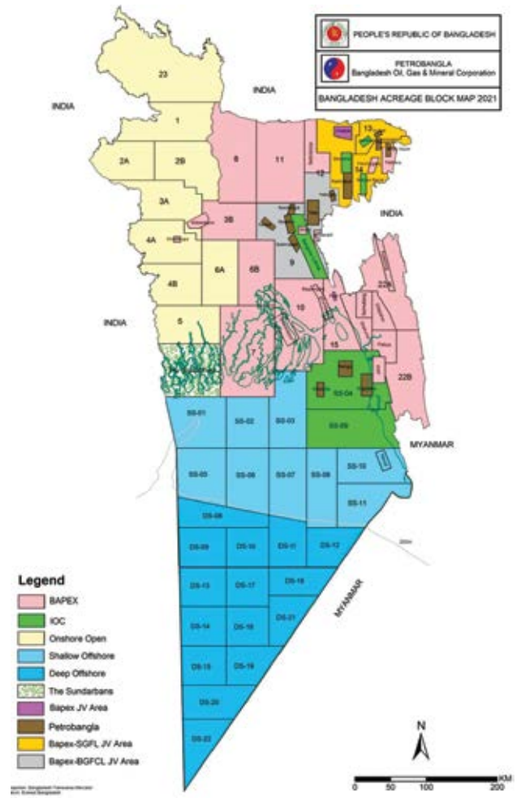
1) Ganges-Brahmaputra delta system with sand-rich fluvial-channel pinch-outs, abandoned channel-fills, levee and crevasse splays, distributary channels, mouth-bars, abandoned delta-lobes, and tidal-bar traps.

2) Onlap sand facies in transgressive coastal settings and sand pinch-outs along the slope.

3) Deep-water turbidite systems: Mio-Pliocene age, sand-rich deposits that occur across most parts of the offshore.

While the wide range of untested stratigraphic plays and traps hold great promise, there are equally promising structural plays and traps in the Bangladesh offshore sector.

Geological and geophysical studies suggest the deeper portions of the Bay of Bengal (Hatia Trough and Rakhine Basin) show a well-developed, gravity-controlled, deep-water fold belt. In other parts of the world, these fold belts form important oil and gas provinces (e.g., Gulf of Mexico and Niger Delta).



Map of Bangladesh showing oil and gas exploration blocks. The two IOC-held blocks in the shallow offshore (SS-04 and SS-09) are being explored by India's ONGC Videsh Ltd and Oil India Ltd.

NEW SEISMIC ACQUISITION

As a strong indication to Bangladesh's offshore prospectivity, the 2023 S&P Global Commodity Insights report states ExxonMobil is in talks with the government of Bangladesh to explore all 15 deepwater blocks under the new PSC model, in addition to possible onshore exploration.

Should the PSC between ExxonMobil and Petrobangla be approved, much-needed 2D/3D seismic surveys of the offshore sector will be acquired. This should highlight low-amplitude closures above listric normal faults in shallow waters that are common to large deltas with high-sediment load. Likewise, in the far southeast of the offshore, poorly defined anticlines and other convergent traps can be expected along the western edge of the Chittagong-Tripura fold belt.

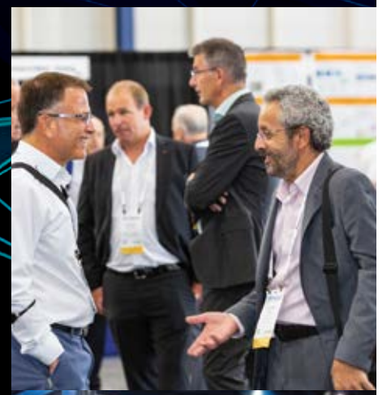
AVOIDING ECONOMIC CONTRACTION AND HELPING THE CLIMATE

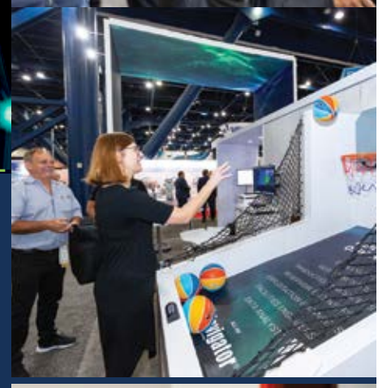
If the present decline in gas production from Bangladesh continues, some forecasts show that coal and gas consumption will be at parity in power generation by 2040 at around 35% each. In order to slow the growth of coal or even decrease its use in the energy mix, Bangladesh has got an alternative and that is ramping up gas consumption from new discoveries.

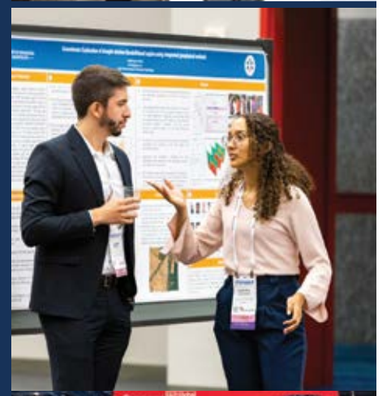
Rather than in some countries where there is nothing much left to explore for, Bangladesh finds itself in a different position where there is potential to make significant discoveries in the offshore sector. Given that international majors have already expressed interest in exploring the offshore area forms independent proof of this.

Against that backdrop, new seismic acquisition, state-of-the-art processing and mapping and interpretation guided by geological modelling over the under-explored Bangladesh offshore has great potential to define stratigraphic and structural traps to be evaluated by the drill bit in the coming years, aided by the drilling program already announced.

Domestic gas production will not only help reduce the dependency on an unpredictable LNG market, but it will also result in a cleaner energy mix and create a more stable path towards economic growth. ■







PHOTOGRAPHY: JORIS EGGENHUISEN VIA TWITTER

SHOULD ACADEMIA CUT TIES WITH THE FOSSIL FUEL INDUSTRY?

We ran a poll amongst our followers to find out what they think and had some interesting follow-up discussions offering different perspectives.

HENK KOMBRINK

"A RIDICULOUS QUESTION." It was one of the comments we got on the poll featuring the question stated above. Nevertheless, we received a total of 370 votes, which is our record number when looking at the polls we have done so far. Out of these votes, a total of 91% voted "No", so against cutting ties between the fossil fuel industry and academia.

It is probably not too much of a surprise to see this result, as our followers are for an important part people who work in the fossil fuel industry. However, looking at those who voted in favour of maintaining collaboration, there were people from academia, both senior researchers as well as PhD students and undergraduates. It shows that there is certainly a mix of opinions in the academic community, even though the mainstream media tends to mainly portray those who are strongly in favour of cutting ties with the fossil industry. And, with a few "Yes" votes from people working in the oil industry itself, there is also diversity of thought within.

DELFT

One university with an active debate on whether to continue receiving money from the oil and gas industry is Delft University in the Netherlands. We asked assistant professor Hemmo Abels for his thoughts.

"I'm fully aware of the complex situation when it comes to societal dependency on fossil fuels", Hemmo said. "However, we see that until today the fossil fuel industry invests a fraction of its profits into researching and accelerating the energy transition. It is too little and it is getting too late. More needs to be done, and soon."

"Money from the oil industry can help facilitate fundamental research into green energy for sure, but the question to many is whether the involvement of universities in oil and gas research will prolong hydrocarbon use rather than speed up the energy transition."

"On another and more practical note", Hemmo continued, "we are receiving increasing levels of funding through the government that is focused on the energy transition. It takes away the need to accept funding from oil and gas for the science we do. At the end of the day, we as a university are limited in our human resources when it comes to performing research. That brings us to the question, is it still ok to accept money from hydrocarbon companies? Maybe not."

The situation in Delft is particular. Even when a company such as Shell will not be able to sponsor research at Delft University anymore, the operator will still have a presence at the university through their majority share in the deep geothermal project currently under development at the university campus.

"This makes the discussion even more precarious as major hydrocarbon companies obviously start to invest more in sustainable resources. Is the investment greenwashing or indeed the serious and needed move to green energy? The wish of some to ban all hydrocarbon companies from our university becomes much less easy to answer this way", Hemmo admits.

Utrecht University protest.

SEDIMENTOLOGY AND INDONESIA

PhD student Enry Horas Sihombing, who voted in favour of preserving ties between industry and academia, works at the University of Bergen in Norway. He recently attended the SEPM Bouma Deep Water conference in Utrecht, the Netherlands.

Enry wrote: "One professor from Utrecht University mentioned that he is currently facing a dilemma because the university is hesitant to accept funding from oil and gas companies. However, most research in sedimentology is funded by the oil and gas industry. And even though deep-water sedimentology has applications beyond oil and gas, such as underwater cables, microplastics, and more, the oil and gas ▸

industry is still the main driver and financial contributor in this field."

Enry, who is from Indonesia, continues in an email: "Indonesia is the second-largest producer of geothermal energy in the world, but the non-competitive electricity price makes this industry unattractive and unprofitable, resulting in a low demand for geologists. The state's electricity monopoly determines the price, which makes it difficult for the industry to do massive hiring."

"If we relate this to academia, most geological research in Indonesia is focused on oil and gas, and coal. These industries still play a crucial role in many people's lives, including the 3,000-3,500 geologists produced by these universities each year. At the SEPM Bouma conference, many were disappointed to learn that the number of geology students in the West has dropped dramatically. However, in Indonesia, the number of students is increasing, and research is still heavily funded by earth resources-related companies."

So, if asked whether research should still be supported by the oil and gas industry, Enry reflects: "Well, because the initiative in the West is now focused on renewable energy, it's okay to abandon funding from oil and gas. However, in terms of size, sometimes we forget that in developed countries, energy transition is still far behind, and we are still at the stage where all funding comes from oil and gas. This may be similar to what happened in Europe 10-20 years ago when companies raced to provide funding to universities."

REFLECTION

Whilst concern regarding the pace of the energy transition is understandable, it seems that universities' ability to cut ties with the fossil fuel industry is also a matter of money. Increased levels of funding from governments, at least in the West, combined with smaller numbers of students signing up for a degree in geosciences, make it easier for academia to conclude that oil money is no longer needed.

This situation is entirely different in countries like Indonesia, where student numbers have increased in recent years and where the government may not have a similar financial capacity to fund more research into the energy transition.

But the question remains; should a university turn down funding from the oil and gas sector regardless of the financial situation it is in? If so, that would then leave academic research to be more dependent on the state. But does that mean there is more academic freedom? In a way, it's not, because government funding preferentially goes towards those topics that are deemed impactful and relevant to society. Whilst that is not wrong per se, it has the potential to undermine scientific freedom where a scientist might be unable to perform her or his research because it is not fashionable, or simply does not come with the potential "impact".

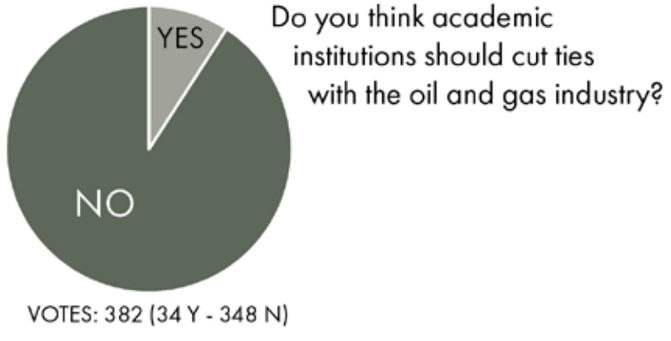
In a way, one could argue that funding of scientific research should not come with any strings attached and be left to the researchers themselves to find the most relevant and pressing scientific problems to solve. That is not the way things work these days, as a researcher in biology recently described to me: "In order for proposals to be granted, we need to involve as many partners as possible to increase the relevance and impact of our research. This includes involving companies. It is being seen as critical."

..in Indonesia, the number of students is increasing, and research is still heavily funded by earth resources-related companies.

If it is key to involve industry to win academic research grants these days, would it not be odd to exclude the industry that is responsible for delivering more than 80% of societies' energy demand?

Why would an oil company support research? Partly because it wants to produce more efficiently, which only has a positive impact on CO_2 per produced barrel. But, on the other side, research will also be funded to potentially find more hydrocarbons. It is a difficult call.

In summary, it is clear that where universities in the West may have more flexibility to fund more research into the energy transition and therefore cut ties with the oil industry, that does not mean countries in other parts of the world will be able to do the same. Moreover, one should also ask the question if research funded with a more politically-driven agenda is always ideal and properly reflects what society needs most. Let the big questions dominate the scientific discourse, which is not only how we transition away from fossil fuels, but may well require an element of how the remaining reserves are being produced as efficiently as possible with the lowest CO_2 footprint. ■



PORTRAITS AND INTERVIEWS

"When people have certain ways to manage a workflow, there is often a natural resistance against change. I really felt that the social skills I inherited from my father and mother were as much required as facts about the new technology to ultimately achieve my goal."

César Patiño - Ecopetrol

TRACTORS AND TECHNOLOGY

César Patiño reflects on his career as a petroleum engineer which brought him to many places and now to Norway.

"REMEMBER, OIL IS A PRODUCT OF NATURE", says César Patiño when we meet on Teams in April. In his role as a delegate for the International Energy Agency Technology Collaboration Program EOR, he feels the importance of highlighting that oil is a source of energy that can be recovered energy-efficiently, at the same time as acknowledging that we have to work towards a more sustainable way of using the product.

César is visiting Norway for a few months to learn about the ecosystem and research being done in the country in the realm of the CO_2 value chain, energy efficiency, and technologies towards EOR – Enhanced Oil Recovery.

He lives in Colombia and works for Ecopetrol, the state oil company that participates in and operates many oil and gas developments in the country. I caught up with César to hear about his career, the current situation when it comes to oil and gas in Colombia, and how the energy transition can be used to produce oil and gas more sustainably.

A COMMON THREAD

César studied petroleum engineering at the Universidad Industrial de Santander in Bucaramanga, which he finished in 1996. "Ever since my BSc thesis, which was on the use of neural networks and artificial intelligence to better predict subsurface properties, I've been intrigued by the use of technology to facilitate our work in the oil and gas sector, ultimately leading into the things I now do with CO_2 abatement and the circular economy", César says.

"My years at Schlumberger, working as a wireline engineer from 1997 to 2006, brought me to places such as Chad in Africa and Mossoro in Brazil. It was a great way to see the world and experience how the oil industry supports the economic development of our communities", he adds. "Progressing a society from a local and closed agricultural system with poor living conditions to an internationally-oriented place with higher standards of living is something that I am proud of."

"When I joined Weatherford (Compact Slim Wireline Business) in Venezuela in 2007, my interest in technology remained and I developed a particular interest in slim hole tools and tractors driving these tools into the borehole."

> "Progressing a society from a local and closed agricultural system with poor living conditions, to an internationally-oriented place with higher standards of living, is something that I am proud of."

"However, despite the technology being available, people did not have the expertise to use it. I saw this as an opportunity and started to involve different members from the geoscience teams. I also decided to invite my team to attend demonstrations of its use, which ultimately resulted in the full implementation of the tools in the field and profits for the business." ▸

SOFT AND HARD SKILLS

César was born in the town of Bucaramanga to a mother with strong scientific and academic interests. "My mother is a biologist with a deep interest in nature", César says. "Since I was a child, I have felt the same passion for study and our natural world." For César, it is not far removed from his studies in natural resources and hydrocarbon technology.

"My soft skills, networking capabilities and open-mindedness are from my father. He worked in the leather industry in Colombia, and I remember going to places with him where he needed to introduce himself to an entirely new group of people with new leather products. The way he got about that forms an inspiration for me to this day, building up new relationships from scratch. It also forms the basis for my management, political and public sector studies."

César Patiño at one of his favourite spots in the Stavanger area; the rock carvings of Fluberget, Revheim. These carvings date back to the Bronze Age (1800-500 BC).

PHOTOGRAPHY: DAMIR GRSKOVIC

The CO_2 value chain requires a source as well as subsurface element. The CO2 Storage Atlas by the NPD is a must-read for the Norwegian Continental Shelf and a similar atlas should be created for any basin where CO2 storage is to take place.

"However, it did take some time to get to this point", César admits. "When people have certain ways to manage a workflow, there is often a natural resistance against change. I really felt that the skills I inherited from my father and mother were as much required as facts about the new technology to ultimately achieve my goal", he laughs.

"NOBODY WILL TURN UP!"

"I have always strongly believed in sharing knowledge and volunteering for the community", César says. "For me, the Society of Petroleum Engineers (SPE) has been and continues to be the main vehicle to do that, but I have also been grateful to be part of AAPG, EAGE and SPWLA organising committees. Being part of the SPE board of directors representing Latin America and the Caribbean was a great experience, a road that started in a student chapter organising activities."

When César had the opportunity to organise a conference dedicated to Heavy Oil production in Colombia in 2010 as the Chairman of SPE's Colombia Section, he did not think about the location to host the conference for long. "It had to be Villavicencio, where most of Colombia's onshore heavy oil activity is managed from", he says.

However, the country did not have the best reputation when it comes to safety and there were concerns that nobody would turn up at the conference. "We had to fight some battles to convince people that it was still the best place to host this", César adds. "Ultimately, when one wants to serve a community, there must be a willingness to go there, because not everybody will have the opportunity to travel."

"It was a great success in the end", César explains. "We welcomed many people from all over the world who were curious to visit the place. There was also a strong element of culture and folklore embedded in the conference, which added to the experience", he says. "In the end, participants didn't want to leave the place as they enjoyed it so much."

> "In the end, participants didn't want to leave the place as they enjoyed it so much."

A COLD PLACE

César Patiño lives in La Calera, a village high up in the mountains to the east of the capital of Bogota. "I love the cold", he says, "and here in the mountains, it is surely much colder and calmer than the busy and general conditions in the capital. It is also close to the Chingaza National Parc. The Spectacled bear *(Tremarctos ornatus)* roams here; I have spotted one a few times when spending time in the area."

PHOTOGRAPHY: DAMIR GRSKOVIC

BREAKING DOWN SILOS

In 2010, César joined Ecopetrol, the national oil company of Colombia. "Given my interest in technology, my positions in the company have always revolved around the integration of data and trying to find ways to bring the different subsurface expertise together. In addition, as heavy oil and enhanced oil recovery is an important part of the upstream business in Colombia, it is no surprise that most of my activities have focused on these aspects of our production", César says.

"We are aware that knowledge is a competitive asset, and to break silos and move towards a routine where knowledge is being shared within the company, I produced what we call the Subsurface Knowledge Platform, in which essential workflows from all disciplines are being captured. It has facilitated an environment where knowledge is shared more efficiently and it also is a way for people to get to know each other", César explains.

> Given my interest in technology, my positions in the company have always revolved around the integration of data and trying to find ways to bring the different subsurface expertise together.

EOR AND THE ENERGY TRANSITION

"For a while now, my remit has also included the question of how we can combine EOR and the Energy Transition in a drive towards a more sustainable way of oil production. For instance, how can we make water management more environmentally friendly and are there ways to reduce the level of energy required to maintain production" César continues.

"This is not only a matter of importance to us in Colombia, it is a matter of importance to the world, because production from existing fields is declining at 8% per year and new field developments are not offsetting this decline. For that reason, it is of key importance to look at innovative ways to sustain production from these existing fields. Even in a scenario in which oil consumption is decreasing, this is still an important thing to do", says César.

"That is one of the reasons why I am involved with IEA's EOR Technology Collaboration Program (TCP), which aims to provide a platform for sharing new ideas to overcome these challenges, and bringing Energy Transition and Abatement solutions together."

Supported by his employer, César now spends 90 days in Norway to learn about the work that is happening in this realm. "There are so many research initiatives running in this country", he says: "The Petroleum Directorate (NPD, Coexistence division), UiS Stavanger, NORCE, Gassnova , Northern Lights, NTNU, UiB Bergen, Innovation Park and several research groups are looking into the matter. My aim is to bring insights together and report this to the IEA such that our global members can ultimately benefit from the knowledge that is being produced here." ■

OIL AND GAS IN COLOMBIA

"People have found a use for oil since the earliest records", recalls César. "Indigenous people used the oil collected from seeps along the Magdalena river as a natural repellent to mosquitos, and special celebrations in the jungle."

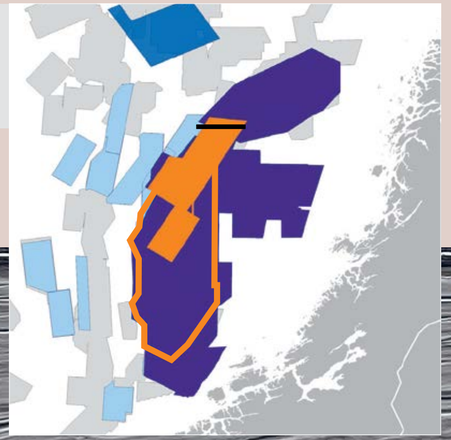
The modern-day oil and gas industry in Colombia was born in this place, which is now known as Barrancabermeja, when wells drilled in 1918 found oil. These wells were drilled in the first exploration concessions granted by the government under the names Barco and de Mares. "There is still oil being produced from the La Cira oil field in the area today", César explains.

Most oil and gas is still being produced onshore, with the Magdalena Valley and Llanos basins as the primary producing areas. "However, there is a growing interest to also explore offshore", César adds.

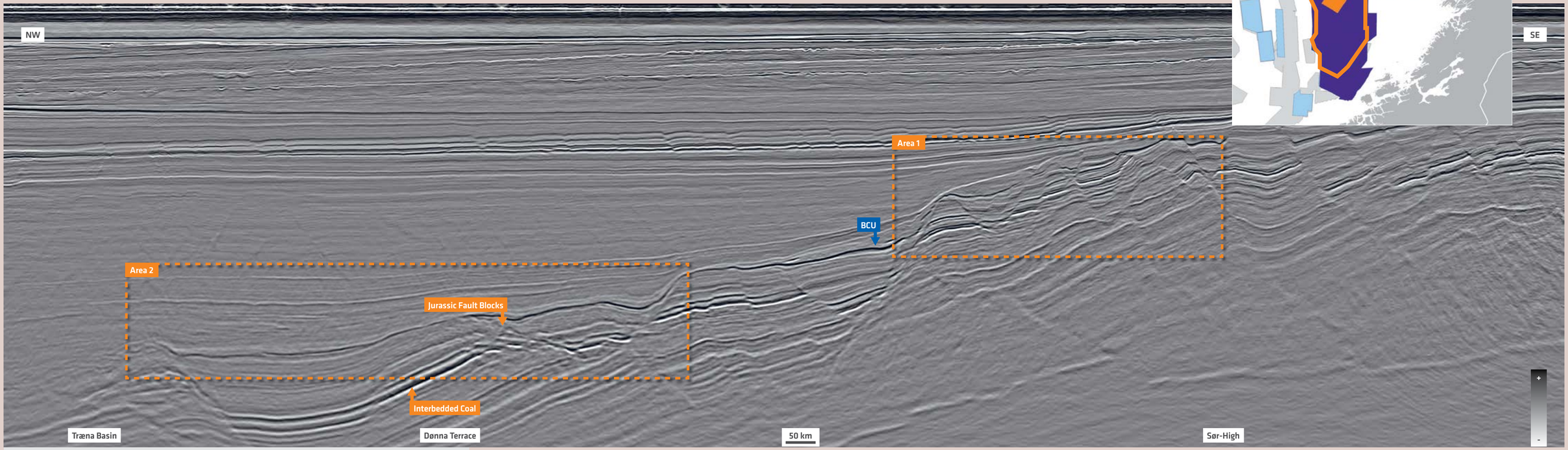
New GeoStreamer X data for exploration, ILX and appraisal in the Norwegian Sea

For more than 10 years, PGS has built a comprehensive and contiguous data library in the Norwegian Sea. A wide range of technologies and workflows have been employed to address the imaging challenges for various subsurface targets. The latest addition to the library is the 2022 GeoStreamer X program. The advanced high-density multi-azimuth data provides high-end exploration data to resolve the imaging challenges present on the Halten/Dønna Terrace and reveal the remaining potential in the region.

A high-quality early output volume will be available at the end of May 2023, utilising data from the new 2022 acquisition and existing GeoStreamer data reprocessed in 2016. The GeoStreamer X stack gives a good indication of the uplift generated with a multi-azimuth GeoStreamer X product in the Norwegian Sea. Innovative acquisition combined with a state-of-the-art depth imaging flow improves data quality. Interpreters and geoscientists get a dataset with improved resolution, reliable amplitudes, better continuity of events and definition of faults, leading to better interpretability.



The GeoStreamer X 2022 survey is shown in orange with the main seismic section highlighted. The survey area for the ongoing GeoStreamer X 2023 and the 2024 program is outlined in orange.



This GeoStreamer X full stack section from the Norwegian Sea is taken from an early-output volume from the 2022 program. The section is depth migrated and includes the Sør High, Dønna Terrace, Ytreholmen Fault Zone and crosses the Urd and Verdande areas. The section represents the dominant Lower Cretaceous (Lysing and Lange) and Jurassic plays (Fangst and Båt Group). Area 1 illustrates an example of fairly shallow and highly segmented Jurassic fault blocks on the Sør High while area 2 displays the Lower Cretaceous basin fill underlain by deeply buried Jurassic fault blocks showing variable preserved Early and Middle Jurassic sections in the Dønna Terrace.

GeoStreamer X in the Norwegian Sea – Improved data quality for risk and uncertainty assessment

GeoStreamer X combines multisensor broadband fidelity and wide-tow source efficiency, with multi-azimuth illumination. The GeoStreamer X product provides high-end data to resolve imaging challenges in the Norwegian Sea, revealing remaining potential and derisking future drilling opportunities.

AUTHORS: KJETIL ROVERUD, STEFAN MÖLLER, ERIC MUELLER AND JENS BEENFELDT, PGS

GEOLOGICAL SETTING AND CHALLENGES IN THE NORWEGIAN SEA

The Norwegian Sea is known for good-quality hydrocarbon reservoirs and complex geology. Tilted fault blocks created by Late Jurassic rifting host prolific pre-rift petroleum plays, which consist of high-quality Jurassic sandstone reservoirs in structural traps. However, improved seismic data has led to an increased focus on marine post-rift deep-water clastic systems and stratigraphic traps in the Cretaceous section. Increased interest on the Cretaceous section combined with exploration potential in undrilled Jurassic structures and potential within the Paleocene and Triassic makes the Norwegian Sea attractive for continued exploration.

Warka, 6507/2-6, Slagugle, and Iris/Hades are all recent discoveries that prove the considerable remaining potential in the Norwegian Sea. High-quality seismic data is key to overcome subsurface imaging challenges and provide an accurate representation of the subsurface. The overburden in the Norwegian Sea may seem simple at first. However, periods of subsidence, uplifting and erosion have resulted in an overburden characterized by high impedance contrasts, rough surfaces, complex velocities, and complex anisotropy. In addition, shallow glacial morphology generates strong noise and multiples, affecting not only shallow targets but deeper targets as well.

GEOSTREAMER X: INNOVATIVE ACQUISITION AND RICH AZIMUTH DISTRIBUTION

The GeoStreamer X 2022 acquisition program in the Norwegian Sea encompasses an area of approximately 6,700 sq. km, with an azimuth orientation perpendicular to the existing GeoStreamer dataset acquired between 2011 and 2016. Together the state-of-the-art depth imaging and the reprocessing of the existing data creates a uniform and large-scale multi-azimuth dataset in the region.

The innovative GeoStreamer X configuration utilises a wide-tow triple source setup that allows for denser sampling in the crossline direction, longer cables for improved Full Waveform Inversion (FWI), and cables towed as closely as possible to the source arrays. In this case, the source array separation was 250 m between outer arrays, and the data was recorded with 14 cables spaced at 75 m intervals (12x7 km and 2x10 km long).

This acquisition setup significantly improves the near-offset distribution and provides rich azimuthal coverage. This enables a step change in data quality in the Norwegian Sea, helping to solve remaining imaging challenges in, for example, complex overburden structures, but also in areas with weaker reflectivity such as the Cretaceous. It also reveals the deeper potential in the region.

A modern pre-processing sequence ensures seamless merging of all azimuths into a single dataset before Q Kirchhoff Pre-Stack Depth Migration (Q-KPSDM). The velocity model will be obtained through comprehensive Velocity Model Building (VMB), including the use of both refractions and reflections for FWI in a multi-azimuth setting. This is crucial for resolving both shallow and deep velocity anomalies, such as channels, shallow gas, or velocity variations at Cretaceous and Jurassic reservoir levels.

DERISKING WITH ENHANCED IMAGING

GeoStreamer X products have proven clear uplift in terms of continuity and resolution of reflectors as well as improvements in the interpretability, definition of the faults, and structural-stratigraphic geometries. Enhanced imaging leads to better interpretation, understanding of the reservoir and reservoir property estimation. This improves risk assessment and reduces uncertainty, allowing a more accurate estimation of subsurface reserve distributions and optimized exploitation strategies.

A high-quality early output volume with a delivery date end of May 2023 is one of the products from the ongoing GeoStreamer X 2022 program. The deliverables for this product include pre-stack gathers, final stacks with up to six angle ranges and velocities. A modern processing sequence has been used for the acquired 2022 data while the legacy data has been picked up from the demultiple shot gather stage.

The data from all surveys was used and split into azimuth sectors prior to 5D regularization and Q-KPSDM with a legacy velocity model. The early-output volume already demonstrates the benefits of a GeoStreamer X solution compared to existing high-quality 3D in the Norwegian Sea, enabling early prospect evaluation half a year before the full integrity product delivery.

Multi-azimuth imaging gives improved signal-to-noise (s/n), increasing fault plane definition and reflector termination against faults (Figure 1). Different acquisition directions affect the imaging of fault blocks and internal reflector geometries (Figure 2). The latter is prominent in the Lower Cretaceous section and underlying deeply buried Jurassic fault blocks, where the difference in reflector continuity between each single azimuth is compensated in the GeoStreamer X product.

IDENTIFYING AND UNLOCKING PROSPECTIVITY WITH GEOSTREAMER X

In the Norwegian Sea, both petroleum exploration and appraisal/development drilling will continue to target more complex plays. This requires higher resolution, significantly improved s/n ratio and AVO friendly datasets that can capture structural and stratigraphic details, allowing for a proper risk and uncertainty quantification assessment of any reservoirs and traps. Recent drilling demonstrates that significant potential still remains in mature inboard locations, i.e. in conventional shallow targets and in field development extensions. Key to evaluating these opportunities is high-quality seismic data that provides a more complete illumination of the subsurface than with single azimuth data.

We have demonstrated that the regional GeoStreamer X data fulfill the requirements for a high-quality dataset in the Norwegian Sea. The data is suitable for exploring new and appraising existing finds. The dataset delivers a clear and more accurate view of the subsurface with improved resolution and reliable pre-stack amplitudes. In addition, the added azimuth helps to understand complex fault structures, lateral amplitude variations and reflector geometry. ■

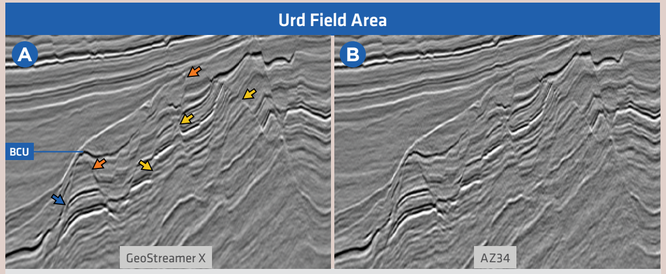


Figure 1: Zoom in on the Urd field area and the Jurassic fault blocks imaged by a GeoStreamer X depth seismic line (A). At an apex depth of ca. 1,830 m below seabed, high-impedance reflectors can be seen. These are caused by interbedded coals in the Åre Fm (blue arrow). Åre sandstones are proven reservoirs along with overlying Viking Group sandstones. A high degree of fault segmentation is obvious and critical in field development strategies. Note the difference in fault plane visibility, fault plane extent (orange arrows), and reflector termination against the faults (yellow arrows) compared with the single azimuth seismic (Azimuth 34) section in (B).

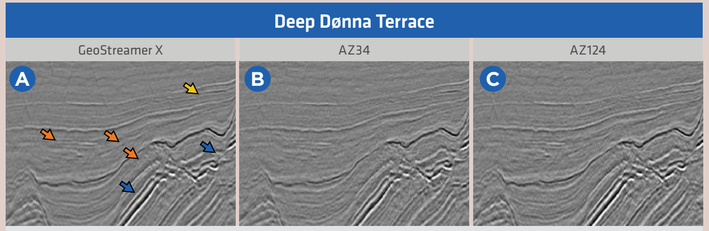


Figure 2: Close-up of the deep Dønna Terrace Lower Cretaceous basin and underlying Jurassic fault blocks in GeoStreamer X (A), single Azimuth 34 (B) and single Azimuth 124 (C) displays. Note the difference in internal reflector geometry, continuity and baselap between the single azimuths and the GeoStreamer X section (orange arrows). Lateral amplitude variations in individual reflectors are indicated. Subtle differences in faulting of the Cretaceous are visible, exemplified by the Verdande base amplitude shut off in the Lower Cretaceous (yellow arrow). High impedance contrast reflectors presumably are interbedded coals in the Åre Formation (blue arrows).

How an oil service company is moving into renewable space

Looking at how Roemex develops their products for geothermal energy production is a good example of the way the oil service sector is expanding beyond the traditional E&P industry.

WE CAUGHT UP with David Halliday and Peter Wilkie from Roemex to hear how their company has found a niche in the geothermal sector and how they are expanding the service in Europe. Roemex has been providing production chemistry services to the oil and gas industry for nearly forty years, but their move into the geothermal sector, delivering solutions for scale and corrosion, is relatively new.

In early 2019, the company was already working on the development of scale and corrosion inhibitors for the geothermal sector for about two years, but it took time to get traction.

Peter Wilkie (l) and David Halliday in front of Roemex' research lab facility in Aberdeen.

"We have seen projects in close proximity where one required scale and corrosion inhibitors quickly, while the other one did not."

"It took a declining injection well in the Netherlands in 2019 that formed the key moment for us", David recalls. Roemex was called for help. "We fixed the problem, injection could restart, and the client was happy", said David. Since then, the Aberdeen-based company is now involved with more than 10 geothermal projects in the Netherlands, where it assists with corrosion and scale mitigation.

NO TWO BRINES ARE THE SAME

"Rather than relying on products taken from our portfolio used in the oil field, we saw early on that the geothermal sector required another product type", David explains. "The main reason for that", as Peter filled in, "is the fact that oilfield inhibitors used in brines do not have the same behaviour as they do when in a hydrocarbon environment."

"Formation water can be corrosive", says Peter, "especially because of the CO_2 dissolved in the brines." Combined with flow rates that are seven to eight times as high as in an average oil well, it is no surprise to see that the materials in a geothermal doublet are put to test from day one and that only the highest-spec materials can withstand corrosion.

"However, it is too simple to state that every geothermal project needs the same level of support", David adds. "We have seen projects in close proximity where one required scale and corrosion inhibitors quickly, while the other one did not", Peter explains.

To provide a tailored service and minimise the amount of chemicals required, the company performs laboratory tests on site in Aberdeen where different brines can be tested against different concentrations of chemicals. The laboratory is part of a project in collaboration with the University of Leeds where, under the umbrella of a Knowledge Transfer Project through Innovate UK, research is carried out on scale and corrosion prevention, both at surface and under subsurface conditions.

PHOTOGRAPHY: HENK KOMBRINK

Testing inhibitors at different conditions in Roemex' lab in Aberdeen.

PHOTOGRAPHY: HENK KOMBRINK

Marco Castillo, who is heading R & D in Geothermal corrosion inhibitors, shows a graph that illustrates how a stop in the supply of corrosion inhibitors does not result in a sudden and rapid increase in corrosion rates. "Even after supply was terminated", he says, "the surface is still protected for a while and will only see a gradual increase in corrosion rate. This highlights the persistency of effective corrosion inhibitors and is key in high flow environments".

"Looking at the different aquifers in the Netherlands from which geothermal energy production takes place, the Rotliegend brines are the ones that poses the biggest challenges because of their mineral content", David further illustrates. "Issues related to precipitation of lead in either the well or the heat exchanger is something that we particularly see in some Rotliegend aquifers", adds Peter.

It seems likely that the surrounding geology is responsible for the composition of the brines in reservoir; the Rotliegend in the Netherlands is overlain by the Zechstein Kupferschiefer in many places, which is a well-known black shale that is characteristic of its metal content.

EXPANDING INTO GERMANY AND FRANCE

The company is now actively trying to expand into other regions in Europe. "We have just come back from a conference in Offenburg, where we spoke to local operators who were forthcoming with very practical issues that they are dealing with on a daily basis", David says.

Each area where geothermal energy production takes place will require a different approach though. "In the Munich area in Southern Germany, water production takes place from a reservoir that is considered an aquifer for drinking water, so that puts a very stringent set of rules in place", David adds as an example.

The company hopes to perform a trial in the Paris area later this year, another geothermal hotspot that has been operating for many years. "We think that we can make a difference here, because we have focused so much on making our products more sustainable", David says.

It takes time to develop bespoke chemistry, time to undertake performance and compatibility testing. More crucially, it takes time to establish relationships and build trust, admits David. For the team at Roemex, that time is invested, and that's what doing business is all about. ■

GEOTHERMAL ENERGY

Geothermal pumped well power projects

Elliot Yearsley

Geothermal pumped-well power projects are a growing niche within the larger geothermal industry, contributing approximately 1000 MWe of installed generating capacity to the global energy mix.

These projects utilize the moderate temperature range of geothermal fluids between 100-190°C. Below this temperature, geothermal fluids are generally used for direct heating and above this the fluids are produced as steam and water with the steam providing the motive force in power generation. Pumped-well power projects maintain the geothermal fluid in single liquid phase throughout the production, power cycle and re-injection processes.

Pumped-well geothermal projects utilize "binary" power plant technology which consists of Organic Rankine Cycle (ORC) heat exchangers. The geothermal fluid is pumped from the wells through the ORC units and re-injected back into the subsurface reservoir. The working fluids used in the heat exchangers are re-cycled and do not come in contact with the geothermal fluids. Binary units are also sometimes used to produce power from the separated water of high temperature geothermal resources.
This article is the first of a series of three installments that will cover a range of topics including a global overview of operating pumped-well projects and subsurface characteristics (this article), pump hydraulics and energy conversion (second in the series), and economics and emerging technologies.

Global Overview of operating projects

Pumped-well geothermal power projects are primarily located in the Western U.S., but growth of these type of projects has occurred in recent years to include Europe, Turkey, and Honduras.

In this overview of operating pumped-well projects, installed capacities are given in Megawatts electric (MWe), sometimes referred to as nameplate capacity. Pumped-well projects consume 20-25% of their gross electrical generation for own use (mostly for the pumps). Net generation delivered to the power grid is also determined by on-line availability, which varies from 70-90% for most of these types of projects. Generation data is stated in Gigawatt hours (GWh), net delivered to the grid (if available).

Nevada and the Western US

Largest concentration of geothermal pumped-well power projects in the world, spread over some 15 fields.

Largest pumped-well project in the world is McGuiness Hills, with installed capacity estimated between 150-170 MWe (gross).

The Steamboat geothermal complex is second in size with 80-150 MWe installed capacity.

Most of the Nevada projects produce fluids in the range of 120-180°C, however Nevada also contains the lowest reported resource temperature (~100°C at Wabuska) of any pumped-well geothermal power project worldwide.

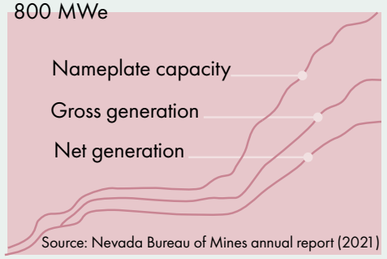
The prolific **Basin and Range geothermal province** in Nevada is attributed to the high heat flow and extensional tectonic setting of the region.

Most of the geothermal activity in the region occurs along faults and cannot be attributed to any recent shallow magma sources. Extensional faulting is required to generate productive geothermal systems, with the fault zones enabling both the upflow of hot fluids and the high permeability characteristics of these systems.

Much of the geothermal production in Nevada comes from **Miocene age volcanic or sedimentary rocks**, although production ranges from Pliocene alluvium to Mesozoic crystalline basement. In general, the geothermal production zones are between 500-1500 meters in depth.

~720 MWe
installed capacity

Growth of Nevada geothermal sector



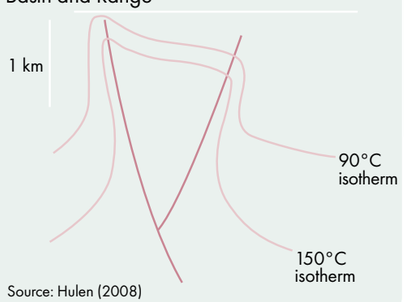
Honduras

One operating geothermal field, the Platanares pumped-well project

Commissioned in 2017 at 35 MWe (gross) capacity.

~35 MWe
capacity

Subsurface temperature anomalies in Basin and Range



Germany

Around 8 power projects in the Bavaria region (**Molasse Basin**) between 3 to 5.5 MWe (gross) installed capacity each. The **Malm limestone** is the primary target of these projects, often containing fracture or dolomitized zones that enhance permeability.

2 projects in the **Rhine Graben** region. The primary target is the **Triassic Buntsandstein**, which consists of interbedded sandstones and claystones with permeability controlled by faulting.

Limited number of geothermal power projects in Europe; exceptions are Velika Ciglena in Croatia (reported as 17 MWe) and Tura in Hungary (reported as 3 MWe).

Geothermal wells for power production in the Molasse Basin and Rhine Graben are generally drilled to depths between 3,500-4,500 meters, significantly deeper than projects elsewhere.

~47 MWe
installed capacity (2021)

Turkey ~300 MWe
installed capacity

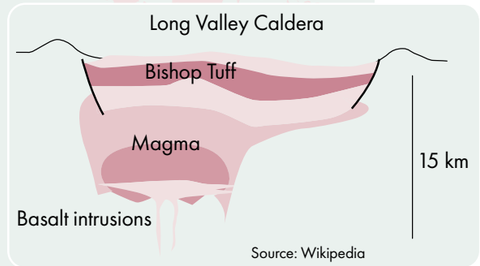
Probably one operating project that uses pumped wells (15 MWe Buharkent project).

High CO_2 has precluded the use of pumping

California ~160 MWe
installed capacity

Ormesa complex in Southern California was the largest pumped-well geothermal project in the world (80 MWe). In recent years the Ormesa fields have been reduced to 36-48 MWe capacity due to cooling in the reservoir as a result of both reinjection of the produced fluids and incursion of cooler water from surrounding aquifers.

The other major pumped-well projects in California are Heber and Mammoth. The pumped-well portion of Heber (known as SIGC) had an original design criteria of 34 MWe, and subsequent updates on the Heber project indicate that it has performed as originally designed over a period of 30 years.



The Ormesa and Heber pumped-well geothermal fields both occur in the **Salton Trough**, a prominent continental rift basin that straddles Southern California and Northern Mexico. The main geothermal reservoir in the Salton Trough are **Pliocene age high poro-perm** sandstones. These sandstones are capable of supporting the high flow rates typical of pumped geothermal wells. Though faulting is known in these areas, porosities of 20-30% and permeability-thickness of 10-60 Darcy-meters (D-m) are characteristic of the sandstone matrix in these fields.

The Mammoth pumped-well project is located in the Eastern Sierra mountain region of California and consists of approximately 65 MWe (gross) installed capacity, including a recent 30 MWe expansion reported in 2022. The project consists of pumped wells completed in recent volcanic formations of the **Bishop Tuff and overlying lavas**. These formations are **very recent** (< 1 million years) and are associated with resurgent dome activity within the Long Valley Caldera.

Revolutionising shallow geothermal borehole drilling

Increasing drilling rates through the evolution of equipment and techniques.

"WE HAVE BEEN DRILLING in London's complex geology for years now. The progression from completing only one borehole every two days, to now having the capability of delivering two in a single day, is remarkable really, but it certainly has not happened overnight", says Alex Bosch, founding partner of GeoTech Developments (GTD).

When GTD was established in the UK 20 years ago, specialised drill rigs for geothermal drilling were limited. The family business struggled to find a rig capable of delivering the level of productivity they knew should be feasible.

Alex explains: "Our early years of drilling exposed so many shortcomings in the available equipment. We just could not find a rig that would give us the flexibility to adapt our drilling techniques in response to complex geological conditions in the UK. Most rigs were typically optimised for specific subsurface settings or restricted drilling methodologies."

Recognising and responding to the shortcomings, GTD took matters into its own hands and partnered with a manufacturer to develop its own specialist geothermal rig, to its own specs and design requirements. This rig, created out of necessity, provided a significant competitive advantage as GTD expanded its drilling operations over the decades.

> "Every element of the operation was evaluated and developed with equal importance. Some of our most successful solutions were to simplify and resist the temptation to introduce something new, but instead integrate learnings from the gas and oil sector."

One of GTD's drilling rigs in action.

PHOTOGRAPHY: GTD

INNOVATION A NECESSITY

"We field tested, refined, and upgraded our rig consistently, with the sole purpose of increasing productivity and profitability", Alex continues. "In the fledgling years, our industry was commercially brutal, with many contractors touting that the cost per foot was just too expensive and consequently not viable. We knew we had to innovate and develop more efficient equipment and processes to prosper."

"Every element of the operation was evaluated and developed with equal importance. Some of our most successful solutions were to simplify and resist the temptation to introduce something new, but instead integrate learnings from the gas and oil sector. We realised that simplifying systems and processes ultimately led to easier on-the-job repairs. Let's face it, sh*t happens when drilling, the easier it is diagnosed, the earlier parts can be ordered and the quicker a rig turns a profit."

"This approach led us on a path to design, engineer and develop our own equipment for every stage of the installation process, including solids control, PDC drill bits, installation weights, loop reelers, and high-conductivity grout that is easy to pump. Every product, part or individual component has contributed to both small and giant leaps in productivity, which when combined enabled us to deliver projects with consistency, on budget and on time – crucial in delivering value to both our business and our customers", Alex emphasises.

DRILLING IMPROVEMENT MILESTONES

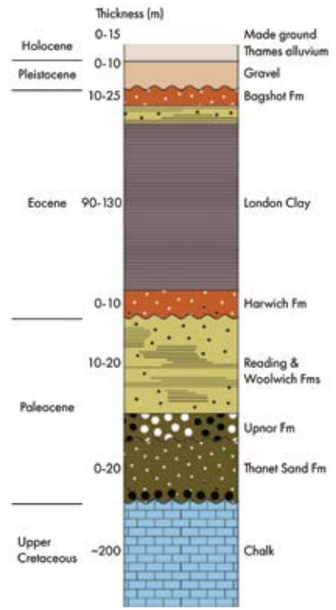
Let us take the geology of London as an example to illustrate the advances made in GTD's drilling techniques. London geology, in simple terms, constitutes a heavy dense clay – the London Clay - deposited on top of a layer of sand, which in turn is underlain by Chalk that contains flint fragments of variable size.

The more the clay is re-circulated when drilling, the more it breaks down and the more it increases the viscosity of the drilling fluids. In addition, the sands at the base of the clay have a tendency to collapse. Finally, the Chalk hardens when drilling deeper into it, with varying amounts of flint further slowing down progress.

"Initially, we used to be casing off all the way down to the Chalk. The first milestone was drilling down through to the Chalk, running casing to depth, and then drilling the Chalk out, all in one day. This initially doubled production and reduced our risk of lost, stuck-in-hole equipment from leaving casing in the ground overnight", Alex explains."

"Our continued development of drilling equipment now allows us to drill faster than ever before and has enabled us to dramatically reduce our drilling times and therefore the disturbance of the boreholes. This allows us to minimise the use of casing required on so many of our projects. So much so that often no casing is required."

"Therefore, we can now drill much smaller holes (5"), which is better for the ground and for the preservation of conductivity. From a drilling contractor's perspective, it increases our ROP and overall productivity. The smaller hole diameter also means reduced grouting costs and a higher up-flow velocity from our mud pumps, which in turn clears the hole faster of the cuttings without needing to use piston pumps. The speed with which we drill has all but negated the need for a centrifuge to remove the fines, as we don't allow enough time for the London Clay to break down further. We also never use additives in our drilling fluid", Alex says.



Simplified column showing the geology of London up to the Chalk.

ACCELERATING THE ENERGY TRANSITION

The achievements in productivity described above are a testament to the importance of innovation, experience, and dedication in the geothermal drilling industry. "I think it is important to share this with the community in order for other parties to benefit from this too", Alex concludes. "We are all working on one thing and that is accelerating the energy transition." ■

A LONDON PROJECT

A recent project requiring 20 x 181 m (594 ft) geothermal boreholes in Greater London, UK, exemplifies this progress. The site had a challenging geology, requiring drilling 100 m (328 ft) of clay, 4 m (13 ft) of sand, pulling back out, changing drill bit and then continuing back down through the Chalk and flint down to the final depth.

However, it didn't stop Alex's team completing not one, but two 181 m (594 ft) boreholes in a single day, where previously this would have taken four days.

The rig used was the GTD GT35 – 300 hp, single head, 16 ton (35,000 lbs) pull back and 6 m (20 ft) x 88.9 mm (3 ½") rods with an internal flush diameter of 50 mm (2").

Using only 3 m (10 ft) of surface casing, the rest of the borehole was drilled open hole. The initial clay and sand geology was drilled using a Pink Penetrator® 3-wing PDC bit, down to the Chalk. Then, the string was pulled out to swap to another in-house developed drill bit - a 537 grade rock roller. The drilling fluids were recirculated in a closed-loop system, which contained no additives. The drill cuttings are processed through the company's 'Mud Guzzler' solids control equipment, featuring a shaker, desilter hydrocyclones and large holding tank.

SUBSURFACE STORAGE

"We have to allow for some seepage and leakage of CO_2 to happen from subsurface reservoirs."

Jane Wheelwright - Dynamic Graphics

CO_2 leakage out of a reservoir should be accepted as a risk

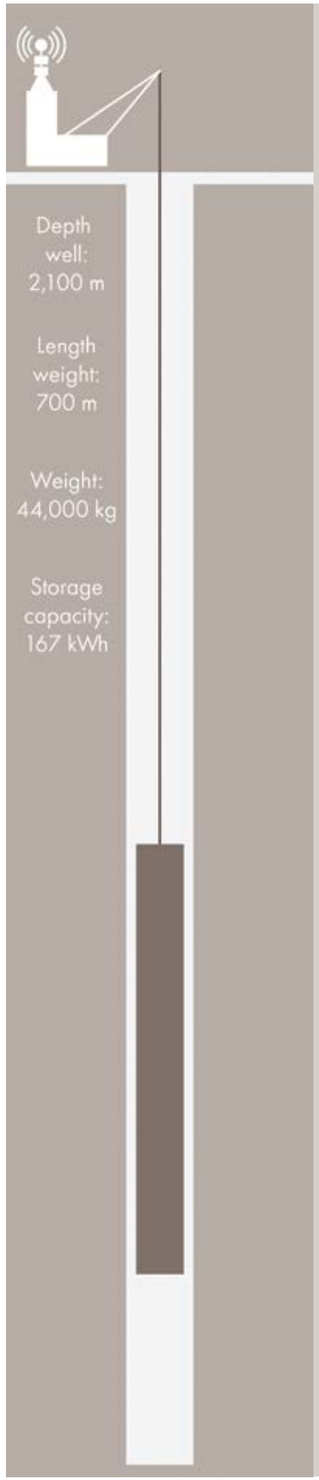
During the latest SEISMIC Conference, Jane Wheelwright from Dynamic Graphics emphasised the fact that 100% containment is impossible to guarantee.

RATHER THAN TELLING PEOPLE that no CO_2 will ever leak from a subsurface reservoir, geoscientists should rather use their expertise to explain that there are always risks associated with drilling wells and injecting fluids in the subsurface.

Even though this message might be a little more complicated to convey, it will prevent situations where the public will feel misled when a CO_2 leak does occur in a future storage site.

This does not mean that no thorough screening is required to find the most suitable injection site and that CO_2 can just be injected anywhere, but a 99% containment probability should not be the showstopper. At the end of the day, it is very much the question if the CO_2 that leaks from a reservoir at around 2,000 m depth will ever make it to surface. In addition, even if it happens, is it a disaster? CO_2 is not a toxic gas after all.

In that light, Jane Wheelwright's comment during her short talk at SEISMIC 2023 was spot on. Geological studies cannot forever continue with the aim to de-risk a storage site towards a 100% probability of containment. It never will, especially combined with potential leakage paths along wellbores. Instead, let's articulate geological risks better. ■



Using old wells as gravitational energy storage devices

Renewell aims to use excess energy to lift a weight in abandoned oil and gas wells that can be lowered again at times of energy demand.

THE TICKET ITEM in the energy transition is the efficient buffering of energy in order to overcome the intermittent nature of solar and wind. Old wells can help with that, as company Renewell from Bakersfield in California aims to do.

Only in North America, there are around 2 million idle oil and gas wells. With an average depth of around 5,700 ft or 1,750 m, these boreholes offer a greater vertical range than any building in the world can provide.

By fitting a weight consisting of old tubing and a high-density filling, occupying about a quarter of the length of the well, the company estimates that a single well has got a 168 kWh storage capacity. Implementing this simple technology to a significant part of idle US wells will result in a total storage capacity of 108 GWh, which is about 90% of the US's energy storage needs by 2050 according to the company.

Not all wells will lend themselves for this solution because of the non-vertical nature of some wells. This may lead to friction and loss of efficiency. At the same time as fitting the well with the Gravity Well technology, Renewell also aims to seal off the well to overcome the problem of methane leaks, an issue that contributes significantly to GHG emissions after well abandonment. ■

More information at: renewellenergy.com

Boring? Maybe not so boring!

Whilst the Triassic Bunter sandstone in the Southern North Sea may be perceived as homogenous, a lack of data combined with recent insights rather shows the opposite.

"IS CO_2 STORAGE in the Triassic of the Southern North Sea a matter of plug and play", asked Ronny Parr from the North Sea Transition Authority the audience at SPE's Seismic 2023 Conference in Aberdeen in April.

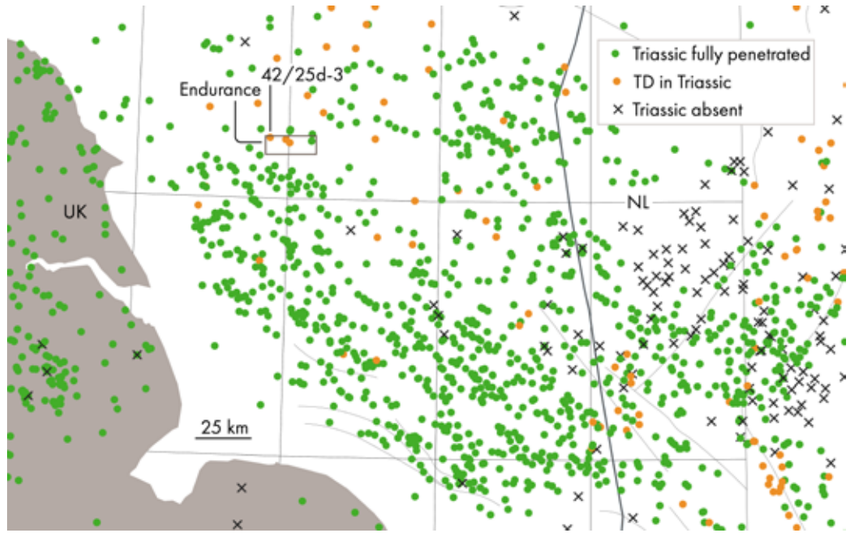
Even though the Triassic has been drilled many times in the Southern North Sea, the far majority of these wells were not targeting this succession and aimed to drill through the succession of red beds, carbonates and evaporites as quickly as possible to reach the Rotliegend and Carboniferous reservoirs below.

Now, many years after the gas drilling bonanza in the Southern North Sea (SNS), it is the Bunter Sandstones that are now the primary target for carbon capture and storage projects, with the Endurance project being the most advanced example of it.

There are a few good reasons why the Bunter sandstones are considered a good candidate for storage. As Ronny put it at the start of his talk: "It is a large aquifer, it has many culminations in the SNS, it has a proper thickness and a great top seal."

However, data are scarce. Compared to 100+ cored sections in the Rotliegend, there are only 20 wells with core in the Triassic of the SNS. Most of those are also clustered where the Triassic fields were located – along the basin margins. To make matters worse, there are only two cores that have sampled the overburden of the Bunter reservoir.

Based on a regional seismic interpretation exercise around the Endurance site, Ronny further showed that the Bunter is more complex than some may anticipate. Comparing two locations in the area of the Endurance site, he showed that the top of the Bunter reservoir has got opposite phases, pointing to large impedance contrasts at top reservoir level.



There are plenty of wells that penetrated the Triassic in the Southern North Sea, but how many have the good quality data required for a decent carbon storage assessment of the Bunter sand?

FACIES CHANGE OR SALT PLUGGING

In between these two places, he identified a seismic feature he marked as an "Inward Dipping Reflector" (IDR). Even though there are still questions around what this IDR may actually represent, one hypothesis Ronny came up with during his talk is that it could represent a change in facies within the Bunter Sand. He based this observation partly on the curved nature of the IDR when mapped spatially. As he said; "I may have tried to do internal facies mapping within the Bunter for the first time."

Another explanation for the phase reversal, as explained by Jon Gluyas and Usman Bagdu in their paper on the Endurance site, is the plugging of the reservoir by halite, which is a common occurrence in the SNS Bunter sandstone. The phase reversal had also been identified in previous research done on Endurance, and was linked to salt plugging at the time. On that basis, the Endurance site was interpreted as containing high porosity sands, with the Bunter sands to the north, south and west being salt-plugged. This concept was "proven correct" when 42/25d-3 was drilled on the Endurance closure in 2013, which also found good-quality reservoir as expected.

In other words, the Triassic is surely not boring. ■

call for papers

We are pleased to announce the call for abstracts for our upcoming conference on new energy and low-carbon systems. The 1st edition of the **#NEXT** conference will primarily be focusing on the subsurface component of the value chain in new energy and low-carbon systems within hydrogen, CCS, offshore wind, and geothermal.

A key enabler in the energy transition is increased multi-disciplinary subsurface understanding. The number of "New Energy Players" in the North Sea is accelerating, fostering the emergence of new ways of working and the evolution of new business models through collaboration and coordination across the entire new energy value chains.

BACKGROUND

A major energy shift is gradually unfolding on the Norwegian Continental Shelf (NCS), with the recent announcement of the 4th CCS licensing round for carbon storage by Ministry of Petroleum and Energy and Norwegian Petroleum Directorate (NPD). The Northern Lights project will offer transport and storage of CO2 as a service across borders and is expected to start commercial operations next year. Denmark and the UK have also recently announced progress in their CCS initiatives. Offshore-wind farm areas are being evaluated on the NCS, as well as in the UK, Denmark and the Netherlands. The Norwegian Government recently announced the first competitions for two offshore wind areas, the Sørlige Nordsjø II and Utsira Nord. With application deadlines in August and September this year, respectively, we can expect the first licences to be awarded by the end of the year. Looking further out, the Norwegian Water Resources and (NPD have identified 20 additional areas on the NCS that might be suitable for offshore wind farms. Site and license activities, including risk identification and assessment as well as monitoring and drilling injections wells for CO2 storage, are activities emerging on NCS and adjacent areas.

The North Sea and the Norwegian Continental Shelf (NCS) are **excellent laboratories, that power cross-border knowledge sharing and collaboration.** There is a broad variety of sediment composition on the NCS, including shallow geology, as well as regional and stratigraphic changes, providing new energy opportunities, but these can also pose risks and challenges. With more than 50 years of exploration and 25 years of storage experience on the NCS, technology and geoscience knowledge transfer play a crucial role in the new energy transition.

TOPICS

The **#NEXT** conference will cover a wide range of new energy digital solutions, strategies, and subsurface evaluations within new energy systems like hydrogen, CCS, offshore wind, and geothermal. We are looking for abstracts covering the following **topics:**

- New Energy and low-carbon strategies, business models, and innovation.
- North Sea cross-border knowledge sharing. Global offshore and onshore use cases and analogues.
- Improved workflows and new digital solutions, such as integrated analytics, ML/AI etc, for next-generation energy systems.
- Shallow geology, and its implications for offshore wind infrastructure.
- North Sea as a subsurface geothermal energy engine.
- Subsurface assessments and risk mitigation studies for North Sea CO_2 and hydrogen storage sites.

ABSTRACT DEADLINE: 28th AUGUST

We encourage abstracts on showcases from energy companies in collaboration with technology companies and/ or vendors. We also encourage academia and start-up companies to submit abstracts.

For more information, visit:
geopublishing.no/event/next/

NEXT
new energy subsurface

call for papers

DEADLINE: AUGUST 31 2023
CONFERENCE DATES: OCTOBER 24-26 2023

GEOPUBLISHING.NO/EVENT/NEXT
LOCATION: BERGEN, NORWAY

The world's first storage project of 100% hydrogen in a sandstone reservoir

RAG Austria starts storage project of green hydrogen into depleted gas field.

AFTER MANY YEARS of preparation, last week saw the start of injecting 100% hydrogen into the Rubensdorf gas reservoir, onshore Austria. The injected hydrogen is generated through the electrolysis of water, for which the energy is supplied by solar power.

The so-called Sun Storage project started in 2013. It first trialed the mixing of 10% hydrogen with the injected natural gas into a smaller depleted gas field in Austria, Lehen. Around 1.2 million m^3 was injected this way.

The selection of Lehen as a test candidate rests on the facts that it is small and isolated, has good permeabilities of between 600 and 1,000 mD, good porosities of around 25% and there is a gas infrastructure already in place. In this video, reservoir engineer Anitha Andiappan from RAG Austria explains the main results from the work done on Lehen and the associated laboratory tests.

DOUBLING OF PERMEABILITY

Pressure transient analysis performed during the injection tests into the Lehen reservoir pointed to a doubling of permeabilities from an initial 602 mD to around 1200 during injection of the hydrogen mix. Anitha explained this by the sweeping of residual water that had accumulated around the former gas production well by the injected hydrogen. "It is not an uncommon phenomenon", she added. With the skin of the well also getting smaller due to injection, well performance improved due to the injection.

Reservoir temperature was measured too. Anitha showed that injection of the gas mix caused a drop in temperature of around 2 degrees to 37°C, which stabilizes again to the ambient 39°C of the reservoir. Based on that observation, she concluded that no apparent geochemical changes were taking place in the reservoir.

This was confirmed by laboratory tests whereby samples of representative reservoir rock were exposed to a mixture of 75% wet hydrogen. As no reaction seams or dissolution of minerals were observed, Anitha suggested that the injection of hydrogen does not change the fabric of the reservoir. Further experimental work whereby 100% hydrogen gases are subjected to reservoir interaction was performed earlier this year as well.

In terms of cap rock integrity, plugs from representative sealing units from the area were exposed to 100% dry hydrogen and methane gases to investigate any differences in permeability of the rock. These analyses found that the permeability to methane and hydrogen of this particular caprock is of a similar magnitude, suggesting that leakage of hydrogen is not taking place at a faster rate than in a methane case.

For further reading, the journal FUEL recently published an extensive review on hydrogen storage in depleted gas reservoirs.

Rubensdorf hydrogen injection facility.

PHOTOGRAPHY: RAG

RUBENSDORF

Now, a 100% hydrogen gas is being injected into the Rubensdorf reservoir. Similarly to the Lehen reservoir test, downhole pressure and temperature gauges will be used to monitor the injection. Flow meters that include a gas chromotograph are also part of the reservoir monitoring project, as well as water sample analysis.

The size of the Rubensdorf storage is still limited; it will store up to 4.2 GWh of solar-generated energy, which is equivalent to the summer surplus of around 1,000 photovoltaic systems on single-family homes. However, it is a first and essential step to overcome the intermittency and seasonality of wind and solar energy. ■

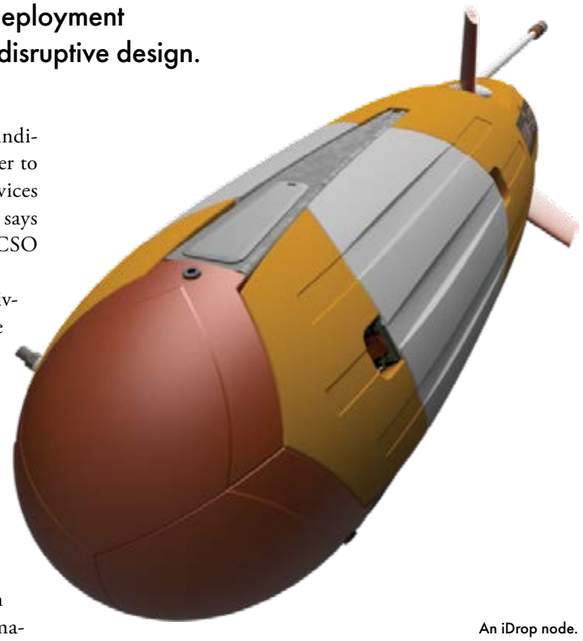
TECHNOLOGY

"We think that there is a big and untapped market for smaller players in the field. Companies that are currently struggling to make the economics of node deployment work."

Kyrre Tjøm - iDROP

Dropping nodes from a supply vessel

Newcomer iDROP aims to make node deployment accessible for smaller players thanks to disruptive design.



An iDrop node.

"WHILE THE NODE MARKET has evolved in the sense that individual nodes have become smaller and therefore lighter to handle", a completely new way of operating these devices has not yet happened. That's what we are aiming at", says Kyrre Tjøm from Norway-based iDROP. He is the CSO and a co-founder of the company.

"At the moment, the nodes market is supplier-driven", adds Kyrre. "There is a higher demand than there is capacity at the supplier's side. For instance, our competitors claim to be sold out for this season. This especially has a knock-on effect to smaller players who will not be able to get a foot in the door under these market conditions."

"In addition, the current ways of deploying nodes is not very scalable", Kyrre continues. "The involvement of dedicated vessels and ROV's form the bulk of the costs, so you need a minimum number of nodes to make the mobilisation worthwhile." In order to further reduce costs, Kyrre sees that energy majors are getting involved in developing the technology and also acquire shares in companies fabricating the nodes.

> "We think that there is a big and untapped market for smaller players in the field. Companies that are currently struggling to make the economics of node deployment work."

"We think that there is a big and untapped market for smaller players in the field. Companies that are currently struggling to make the economics of node deployment work", Kyrre explains. "Our solution will be scalable, flexible and available", he adds. "It will facilitate using nodes in different densities, enable infill campaigns, and extending existing permanent installations."

LESS DELAY

The root of our system lies in the fact that the drop-node – Oceanid™ solution does not require a special vessel. "We aim to use PSV's – Platform Supply Vessels – to drop off and pick-up the nodes", Kyrre says. "All we need is to put an additional container on the PSV – we only need one 20 feet container that contains 250 nodes – and a few crew members to handle the deployment. A small crew and minimal material transfer also reduces the chance of delay or complications related to importing kit for mobilisation. This often forms great hurdles in projects of this kind", adds Kyrre. "Another advantage of using PSV's is that these vessels may already have an established routine when it comes to access to local ports and loading/offloading facilities, so we can piggyback on that."

The nodes iDROP are developing will be able to navigate laterally when being put in the water. Dropped in batches of nine, the nodes will then position themselves into grids of three by three nodes. Once the acquisition has completed, the ballast attached to the node will be released, making it move up into the water column, navigating themselves back to the pick-up point where the vessel will be. Kyrre explains: "The nodes will be able to communicate with each other and are entirely self-operating."

"We are testing the system in the North Sea this summer", says Willy Olafsen, CEO and co-founder of the company. "We also signed a consortium of significant importance recently, giving our development a further vote of confidence. Yes, we are in a rush to get our kit ready for the market, the founder of iDROP says, but we prefer to rush slowly. It's worth waiting for." ■

If you are not using ensemble modeling, you are most likely leaving money on the table

Sebastien Strebelle from Halliburton argues why ensemble modeling helps energy companies to move to more geologically challenging areas

MOST DECISIONS made in reservoir development or management require a three-dimensional numerical representation of the reservoir. Intuitively, that digital representation consists of a single model to which all disciplines, from geophysics to reservoir engineering, contribute to the best of their knowledge.

However, direct measurements of the reservoir are limited to a few boreholes, while indirect measurements, typically seismic data, have low resolution and can be noisy. Because of the sparseness and ambiguity of reservoir data, choices need to be made during the data interpretation and modeling phases of the digital twin construction.

AN EXTREMELY PERILOUS PRACTICE

Interpretation and modeling uncertainties make it impossible to expect a best technical case model to be a fully truthful representation of the reservoir, especially for green fields. The proof is that new production data rarely match the model predictions and require updating the model or rebuilding it from scratch. Making multi-million-dollar decisions based on a single reservoir model, even built by the best subject matter experts using the best technologies, is an extremely perilous practice.

Asset managers need to account for the uncertainties associated with their projects to optimise development decisions and mitigate potential risks. This means that subsurface uncertainties need not only to be identified and quantified for their impact on volume and production, but also communicated.

Generating an ensemble of alternative models capturing those subsurface uncertainties and providing probabilistic forecasts is the key to sound reservoir development and management decisions, helping to deliver results on-target and on time.

To provide reliable probabilistic volumetric and production predictions, ensemble modeling requires four fundamental ingredients:

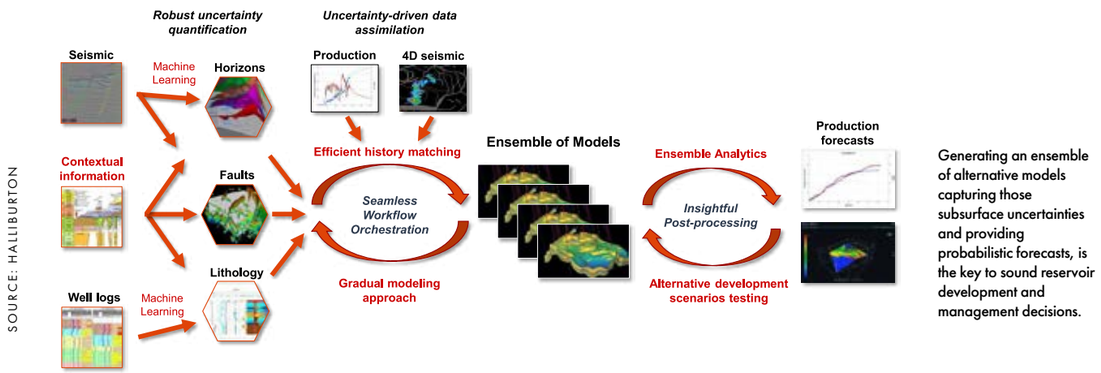
1. Seamless workflow orchestration; flexible enough to offer a large variety of modeling options and parameters, but with sufficient user guidance to avoid the complexity and error-proneness of conventional workflow management solutions based on computer programming principles.

2. Robust subsurface uncertainty quantification: using machine learning-based solutions for interpretation automation and uncertainty assessment, removing personal bias, coupled with the integration of contextual information such as regional depositional trends through multiple modeling scenarios.

3. Uncertainty-driven data assimilation; offering fast and efficient algorithms for production and 4D seismic data integration that minimise the number of computationally intensive flow simulations, while accounting for all subsurface uncertainties. A gradual modeling approach is essential, starting with simple coarse resolution models integrating first-order structural and stratigraphic uncertainties, and then refining concepts and adding geological details as needed.

4. Insightful post-processing; providing clear ensemble analytics for decision support, and allowing the quick testing of alternative development scenarios to explore all opportunities.

In short, ensemble modeling helps energy companies to move to more geologically challenging areas, while decreasing project turnover time from years or months to weeks or days. In other words, if you are not using ensemble modeling, you are most likely leaving money on the table. ■



A ChatGPT-powered personal subsurface knowledge assistant

A new approach provides a natural language geo-bot, powered by ChatGPT, combined with automatic document search of subsurface document stores.

DURING MEETINGS, we often encounter detailed and specific questions, such as whether a particular well had shows in the Jurassic, why a licence was relinquished, or if there are any down-thrown traps near a prospect. Or, what was the porosity in the Sleipner Formation in this or that well? Unfortunately, finding the necessary information is a time-consuming process that involves searching through large in-house data stores or government web pages.

Once the relevant document is located, it must again be searched for the required information. By the time the answer is provided to the meeting attendees, they may have moved on mentally and physically. Wouldn't it be great if we could find a way to make this process more efficient?

Late 2022, a new large language model (LLM) called ChatGPT emerged and forever changed the way we approach text knowledge retrieval and processing. With this amazing technology, we can now ask natural language questions and receive concise and accurate answers for a wide range of topics.

However, there are also some drawbacks to using LLM's. For instance, if they lack sufficient information about a topic, they may provide incorrect answers - hallucination. Additionally, they are not trained and therefore cannot retrieve information and documents in your in-house or government data stores. Furthermore, it is prohibitively expensive to train these models from scratch. That's where the geo-bot project comes in.

AN AI ASSISTANT

The geo-bot project aimed to develop an assistant that overcomes the challenges of text knowledge retrieval and processing by combining the strength of a semantic search engine with the power of a large language model such as ChatGPT.

The Fabriq platform has created the first such geo-bot for the oil gas industry and will soon be available for public testing. This platform has ingested licence relinquishment reports, wikis, final well reports and more into a semantic search engine. This allows terms and concepts to be related to each other across the entire document corpus. ChatGPT then uses the semantically retrieved information to provide the most relevant answer to the user's query.

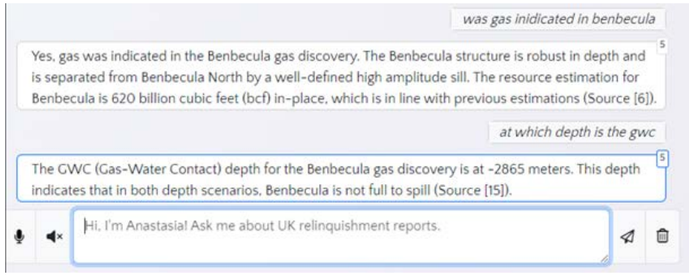


IMAGE: DALL-E

Was there any gas in Benbecula?

Which of these envelopes contains the right information?

With this AI assistant, geologists can easily access knowledge about documents that are in-house or were not part of the training of the large language model. For example, they can ask the bot to summarise the findings of a particular production license. The bot can even create a list of prospects that share similar characteristics, such as being a four-way or being AVO-supported.

We recommend that you test out the new assistant and other upcoming AI-driven language tools. The technology is not yet perfect, it may occasionally miss key information, retrieve the wrong document, or even hallucinate. But it is undoubtedly a significant time-saver when it comes to obtaining a quick overview of a topic or document that has been ingested.

One can easily imagine a future where in a meeting everyone can quickly access readable, contextualised, and relevant information in real-time. We are not there yet, but these subsurface knowledge bots are a big step towards such a vision. ■

Jesse Lord – Kadme
Peter Bormann - ConocoPhillips

Directional drilling is going Wild

US-based company successfully drilled W lateral, pushing the ability to run casing and tools to the limit.

TWITTER CAN BE A GOOD SOURCE OF INFORMATION as to what is going in the oil and gas sector, especially in the US. There are a few people from the greater Houston area who frequently post on what is happening in the "field". One of those people is Collin McLelland, who tweets under the name @FracSlap. He recently retweeted a post from @Tejanobrown, another Twitter reporter from the Permian who is also known as De La Rosa.

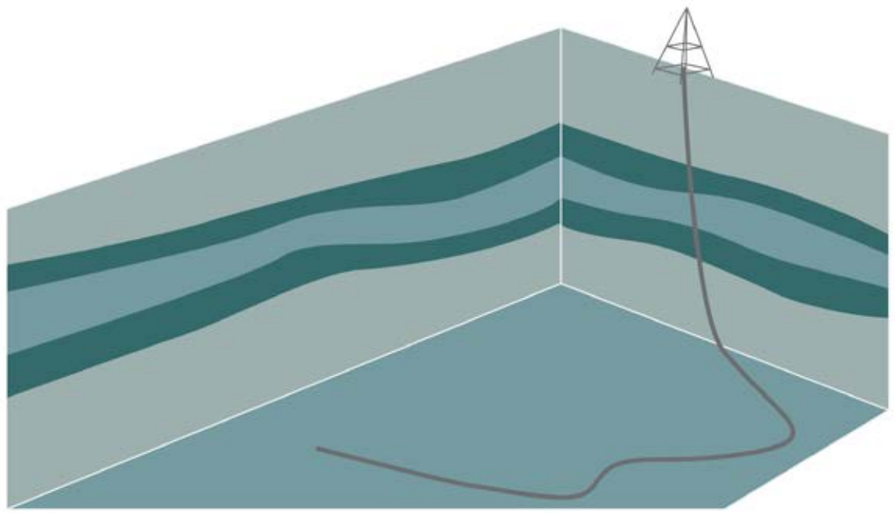
De La Rosa shared a video from a company called MS Drilling, headquartered in Conroe, Texas. In the video, the company shows that it recently completed drilling a W-shaped well in South Texas, the first of its kind in the area. As one person commented on the post: "I wish I could have done some of this 40 years ago."

Not everybody is impressed though. Dayne Kells from Canada replies that Norsk Hydro wells drilled in the 1990's had similar paths – which will be interesting to find out. He added that these wells were a nightmare when it came to matching tractor speed and coiling speed. Another Twitter member suggests that these wells are a great way to steal Venezuelan oil from Guyana.

Joking aside, the complex paths of these wells clearly demand a lot of technology to be drilled, logged and completed properly. "They are pushing the limits and I hope they got a fishing hand on stand bye", mentions someone else in the comments. Other people emphasise the need for tractors to push tools into the hole. Another speculates that the distal half of the wellbore will need to be a sleeve system, which is backed up by another person commenting that it is hard to understand how this casing run can go smoothly. He adds that some operators in the Permian already struggle to run casing in a normal horizontal well. There is also some doubt as to whether this well design is ever going to be profitable.

It would also be interesting to hear from the operator - which is Chesapeake, according to another Twitter member - what the rationale was for drilling this particular path. As somebody else joked, why not drill a hole from the area right above the point where this complex well landed? The answer must probably be sought in a desire to drill as much productive formation as possible, possibly combined with the presence of a fault in the subsurface? Or is it to miss an unleased quarter acre lot in the Barnett, as another person speculated? ■

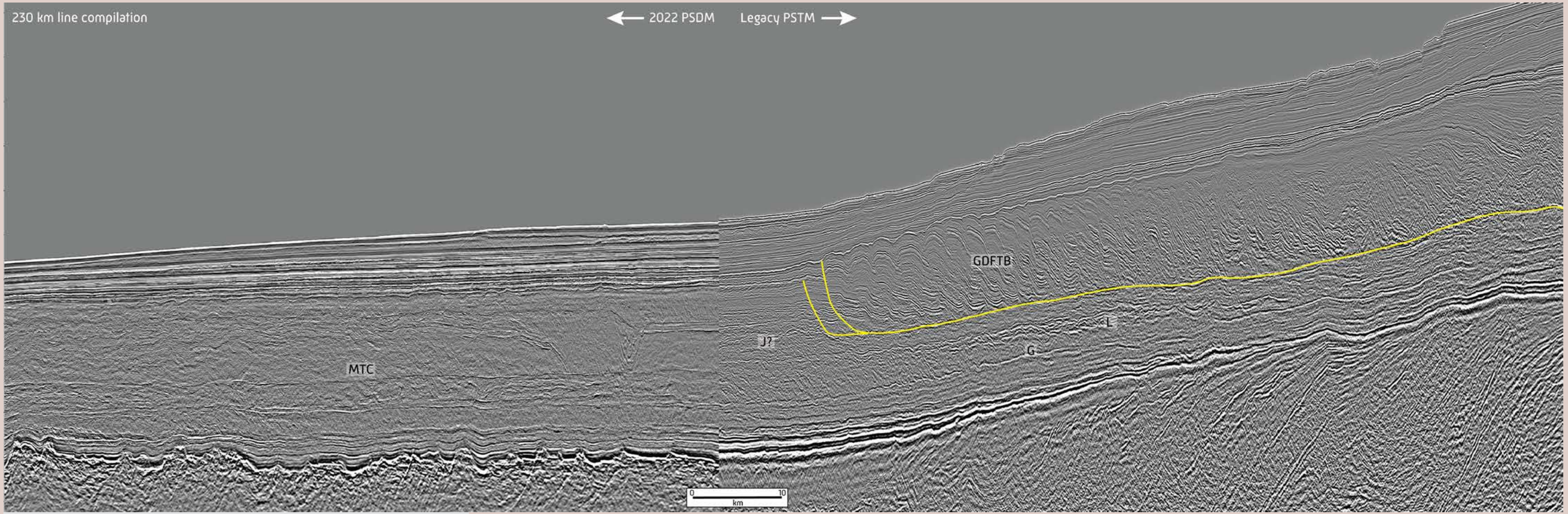
> "I wish I could have done some of this 40 years ago."



Impression of the W-shaped well path as recently drilled by MS Drilling in South Texas. Image redrawn based on video shared on Twitter.

Fast and slow **cat**astrophes trapping slope and basin floor plays

Interpreting geophysicists exploring for oil and gas in stratigraphically trapped channels on the upper slopes of the Atlantic's passive margins are often considered to require cat-like survival qualities, as they use their nine lives to explore a play with a one-in-ten success rate. Here, the key risk, trap, is below seismic resolution. However, there are some confined channel traps that beat the odds and are all beheaded by a lateral regional truncation event that makes it work. And these can be spotted on seismic.



A compilation of Searcher's 2022 PSDM and Legacy PSTM (pseudo depth, meaning compensated for water depth) data from the border of Namibia and South Africa Illustrating the instability in the sediments on this margin. Of the 3 trillion m3 of clastic sediments in this clastic prism, 2 trillion m3 were redeposited as mass transport complexes (MTC) or gravity-driven fold and thrust belts (GDFTB). G = Graff, L = La Rona, J?= Jonker, estimated (analogous positions).

Fast and slow **cat**astrophes trapping slope and basin floor plays

How slumping, sliding and folding of passive margin stratigraphy creates the elements for successful exploration while the latest seismic imaging still enables making sense of the seemingly chaotic result.

NEIL HODGSON, KARYNA RODRIGUEZ AND LAUREN FOUND, SEARCHER

THE DUALITY OF EXISTENCE conjured up by Erwin Schrödinger's cat-based experiment is perhaps best extended into hydrocarbon exploration in the confined slope channel bypass play, because they are both "fantastic" in terms of potential and "monstrous" in terms of being difficult, illustrating that objects can be two opposite things at the same time. It seems unintuitive that the traps envisaged can also be both successful and not successful at the same time until observed with a drill bit; yet how would we know?

Without an up-dip barrier to flow, oil or gas migrating buoyantly up connected sands in a confined slope channel will just migrate up onto the shelf and be lost – like tears in the rain. One such barrier that might prevent flow on to the shelf would be stratigraphic – a part of the channel where no sands were deposited or "bypass zone". In fact, this barrier might be present anywhere up the slope channel system from the basin floor. When the basin floor structure does not avail itself of counter regional dip, as it does, for instance, in the Venus play of Namibia and Pelotas, such a barrier is required for any basin floor apron fan too.

Yet, this represents a ubiquitous and exhausting irritant for oil and gas explorers, as, despite the use of a variety of trap risk focussed proxies such as DHI, AVO, pressure and gradient studies, such a bypass is almost always sub-seismic resolution, and just one thin cat-burglar sand, a Macavity-like stringer of porosity, will be away on his paws with the trap.

Fortunately, a variety of syn- and post-sedimentary structural processes can even the odds in the explorer's favour, creating very imageable channel truncation. Formed during either instantaneous or slow and long-lived catastrophes, gravity-driven processes on a variety of scales can create the required discontinuity of the basin to shelf permeability system.

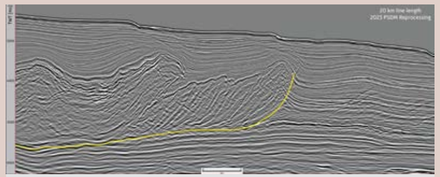


Figure 1: Searcher 2023 reprocessed lines showing slope channels and basin floor fans in front of a Gravity Driven Fold and Thrust Belt offshore Oman. Truncation by the decollement surface create barriers to flow. Here, in Oman this structuring has generated a fold ahead of the first toe thrust appearing soft and bright and is associated with depth conformant flat events.

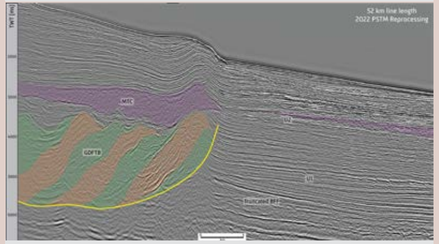


Figure 2: Searcher 2023 reprocessed 2D seismic line showing GDFTB and MTC truncation of lower slope channels and fans in Mahadani Basin SE India. Shelf collapse on this margin is localised and may be related to strike-slip movements seen on near-by lines. U1 and U2 are structurally generated unconformities, more instability generated plays.

SLUMPING AND SLIDING

Syn-sedimentary slumping or gravity sliding can remove a deposited sand, cutting off the thief or create an up-dip barrier to flow. In the Fold-out line and Figures 1 and 2, Post-sedimentary Gravity Driven Fold and Thrust Belts (GDFTB), or Mass Transport Complexes (MTC) in Figures 3 and 4, can also be key to providing up dip barriers. Both of these, syn and post- sedimentary processes are readily imaged on modern seismic, allowing explorers to identify much lower risk traps than are available for the purely stratigraphic play.

END MEMBERS

Clastic prisms building out over passive margins appear to display a spectrum of instability. For instance, the Zambezi, Fly River, or Bengal Deltas are truly stable with few MTC's or GDFTB's despite the deposition of vast amounts of sediment. These clastic deltas often prograde and aggrade with a simplistic sequence stratigraphic perfection. In such settings, the chance of finding syn- or post-depositional structural traps to slope channels is somewhat reduced, although success in the Tano Delta shows that stratigraphic, or sub-seismic structural traps (Jubilee) can work.

At the alternative end of the spectrum are the Orange, Lamu and Rovuma Deltas that exhibit Ozzy Osbourne-like periods of instability (see Fold out). In the Orange Delta, the 4 to 5 cycles of shelf building were followed by its collapse into deep water creating MTC's, several of which are over 500 m thick.

At the end of the Cretaceous, collapse-a-thons, the slowest shelf collapse occurred, keyed onto a decollement surface close to the Turonian source rock, creating the famous Orange GDFTB. Compared to the stable margins, this instability occurs without a huge sedimentation rate, or without a steeper slope to basin floor gradient. In these cases, instability is dominated by mantle convection-driven dynamic topography changing the basin geometry rather than sediment input and given basin geometry.

FIRST FOLD OF THE GDFTB PLAY

In the Rovuma Delta it is this slow-shelf collapse that created the Windjammer "first fold of the GDFTB" play, and the Barquentine "truncated by the first thrust of the GDFTB" play. Another example of a GDFTB occurs in the Mahadani basin of SE India, where the fold belt running down slope truncates not only slope channels and basin floor fans, but also cuts through leveed meandering channel complex running in near strike direction from the huge sediment input of the Bengal fan (Figure 2 and inset).

MTCs are often found associated with the instability of the GDFTB, as seen in Figure 2, and can not only truncate slope channels and basin fans, but also truncate preceding GDFTB as seen in Mahadani Basin in India and Orange Basin of Namibia.

Figure 3: Searcher 2023 reprocessed seismic line with a recent MTC in the Krishna Godavari Basin of East India. Appearing structure and characterless when viewed in its entirety (ca 200km long), in detail at near 1:1 ratio individual thrusts with a thrust angle near 45° can be observed. Note the erosive base of the MTC cutting into and truncating the sand rich basin floor meandering channel systems running almost coast parallel in this basin.

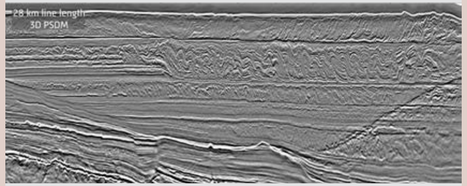


Figure 4: MTC in the Gulf of Papua (PNG) running off the Aure fold belt on the RHS of this image. The individual blocks, and stacked toe-thrust complexes within these packages are well imaged on Searcher's modern 2D and 3D seismic. Note the erosive steps below the individual MTC events. These (and see Figure 3) mark a decrease in the size of the individual thrusts as they flow up the step, maintaining a very level sea floor base. Also, note the variety of flow directions within these MTCs.

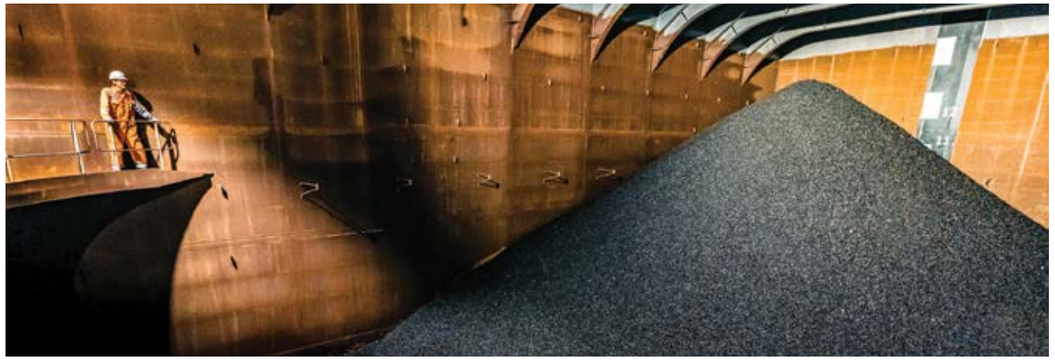
FROM CHAOTIC TO COHERENT

MTC's have in past times appeared as chaotic sequences on seismic, comprising rarely seen coherent blocks in a sea of chaotic, reflectorless goo. However, modern de-ghosted seismic data, when viewed at an appropriate vertical and horizontal scale, can show MTC's to be much more coherent (Figures 3 and 4).

Again, there will be a spectrum between incoherent and coherent structures, yet in these two examples from The Gulf of Papua (PNG) and Krishna Godavari Basins (East India), modern de-ghosted seismic identifies individual thrusts and tilted fault blocks within the apparent chaos. The layering within the MTC's suggest they are mud rich, and they can provide a perfect top seal. They can individually be 100 km in extent, up to 500 m thick and many 10's of km's wide. Thus, they can transfix and truncate the heads of multiple parallel channels in a region at the same time, bringing repeatable success to exploration drilling and trapping truly significant hydrocarbon resources.

COOLER FOR CATS

Ironically, the ability to be able to image the up-dip seal of a confined slope channel or a basin floor fan makes unstable margins more straightforward to explore than those that are not. Catastrophe-derived up-dip structural trapping to slope channels or basin floor apron fans can be readily imaged on modern de-ghosted seismic data, taking the heat from the key exploration risk-element of the slope and apron fan play, and making the trap rather cooler for cats. ■



Last autumn, The Metals Company collected 3,000 tonnes of nodules from the seabed at a depth of 4.5 km. The pilot production was successful.

"It's happening"

The Metals Company aims to extract polymetallic nodules in the Pacific from the end of next year.

MINING COMPANY THE METALS COMPANY (TMC) is sticking to its plans to start extracting deep-sea minerals in 2024. The company's CEO, Gerard Barron, recently told industry website mining.com: "It's happening".

TMC could become the first company in the world to mine nodules on the seabed. They sit on large tracts of land in the Clarion-Clipperton Zone (CCZ) in the Pacific Ocean. The CCZ is considered the largest nodule field in the world.

The CCZ is located between the west coast of Mexico and Hawaii. Nodules are metal-rich concretions that grow on and in the sediments on the seabed.

TMC has referred to nodules as "battery rocks". Chemical analyses have shown that the nodules contain very high levels of a number of metals - mainly nickel, cobalt, copper and manganese - which will be in particular demand in the energy transition.

The company's licence NORI-D represents the world's largest undeveloped nickel deposit, and will contain metals to meet the needs of 150 million electric cars. NORI-D makes up 22 percent of TMC's total resources.

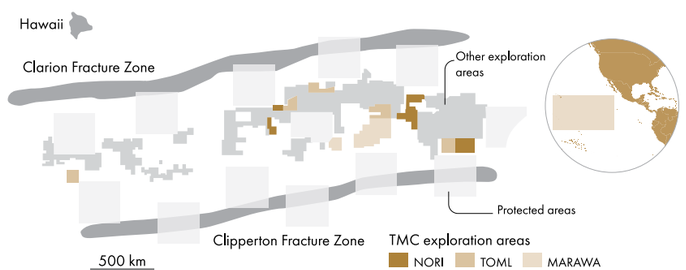
Nodules are advantageous in terms of extraction compared to other deposits in the sea and on land. TMC points out that there is no need for blasting or quarrying in order to retrieve the nodules. They are rich in metals, which results in less residue, they have a very low content of toxic elements and a size that is easy to handle.

DEADLINE

The Clarion-Clipperton Zone is located in international waters, and it is the International Seabed Authority (ISA) that manages the resources in these areas.

Mining.com writes that it is expected that the ISA will start accepting applications from companies wanting to extract minerals on the seabed in July. However, it is not guaranteed that this will actually happen, as the organisation has not yet finished developing a regulatory framework. The ISA is feeling the pressure after the island state of Nauru implemented a two-year rule linked to the United Nations Convention on the Law of the Sea in 2021 – the deadline for developing the framework is July.

Norway is among the countries that have asked the ISA Council to fulfill the seabed authority's mandate and finalise the regulatory framework. However, a number of other countries have stated that more time is needed to be able to acquire the necessary knowledge related to the ecosystems in the deep sea. ■



The Clarion-Clipperton Zone, indicating protected areas and exploration licences.

PHOTOGRAPHY: TMC; MAP: MODIFIED AFTER TMC

10 can turn into 1000

The mapping of sulphide deposits on the Norwegian continental shelf has only just started. There is reason to believe that there are far more than the ten that have been identified so far.

HYDROTHERMAL CHIMNEYS are a spectacular sight. They were first observed in the Pacific Ocean in 1979, and in Norway at the Jan Mayen hydrothermal fields on the Mohns ridge in 2005.

The hot springs and chimneys can be found where boiling mineral-rich water has made its way up to the seabed. In the face of cold seawater, minerals are deposited as sulphides. So far, ten sulphide deposits have been detected along the Mohns and Knipovich ridges on the Norwegian continental shelf.

From a resource perspective, it is the inactive, extinct fields that are most interesting, both because it is technically demanding to operate in extreme temperatures of active smokers, but also because significantly more life exists around these sources.

There is good reason to believe that there are many inactive fields yet to be discovered. In January, the Norwegian Petroleum Directorate (NPD) published the resource assessment for minerals in the deep sea. They reported large, present resources.

During the seminar **Accelerating Deep Sea Exploration** in Bergen in April, NPD statistician and one of the contributors to the resource assesment, Hans Martin Veding, was able to say that - under certain conditions and assumptions - there can be around 1,000 sulphide deposits spread over five geographical areas along the Norwegian part of the spreading ridge.

This figure has been adjusted for sedimentation – it is assumed that many deposits will be so deeply buried by sediments that they are out of reach. This particularly applies to the areas east of the spreading ridge, which have been supplied with sediments from the Barents Sea.

Active chimneys at the Fåvne field on Mohnsryggen spew out hot, mineral-rich water from underground. The chimneys are colored yellow-brown by bacteria that live by oxidizing iron.

The figure is also based on an assumption that the frequency of sulphide deposits is 9.5 per 1,000 km^2 – a figure that is based on knowledge from both the Norwegian and Russian continental shelves. The NPD specifies that the figure is uncertain, and in the report they have presented several estimates.

> **"..under certain conditions and assumptions - there can be around 1,000 sulphide deposits spread over five geographical areas along the Norwegian part of the spreading ridge."**

ACADEMIC VERSUS ECONOMIC

Rolf Birger Pedersen, professor and head of the Center for Deep Sea Research at the University of Bergen, presented a much higher figure during the seminar, but his number is more academic than economic.

Based on the assumptions that there are 10 active hydrothermal springs in the Norwegian-Greenland Sea at any given time, that sea-floor spreading has been going on for 50 million years and that an active spring has an average lifespan of 10,000 years, Pedersen believed that a total of 50,000 sulphide deposits occur in the area.

This calculation, therefore, does not take into account what is possible to find from a resource perspective. Many of the deposits will be buried deep under both sediments and lava.

However, both lectures emphasised that the resource potential on the Norwegian continental shelf regarding sulphide deposits is large and that academia and industry have a big task when it comes to finding these deposits. New technology and surveys will be essential for successful exploration. ■

PHOTOGRAPHY: CENTER FOR DEEP SEA RESEARCH

A national team for increased knowledge in the deep sea

Fifteen partners from industry and academia have joined forces to close knowledge gaps regarding mineral resources in the deep sea. In spring, they will set out on their first voyage in the Norwegian Sea.

"THIS IS COLLABORATION across disciplines, and both industry and academia are involved in order to utilise the expertise we have in Norway", said Anette Broch Mathisen Tvedt, CEO of Adepth Minerals, during the seminar **Accelerating Deep Sea Exploration** in Bergen in April.

She presented EMINENT, a research project that was awarded approximately 6.5 million USD at the end of last year to accelerate the acquisition of knowledge and answer key questions related to the possibility of establishing a new industry that can help supply critical minerals for the energy transition. The total budget is around 13 million USD; Tvedt is the project manager.

Adepth is one of four Norwegian companies that has positioned itself as an exploration company and technology developer ahead of a possible upcoming licensing round for deep sea minerals on the Norwegian continental shelf.

Increased understanding of the deep sea and its geology, environment and resources is essential ahead of possible future extraction of the mineral deposits on the Norwegian continental shelf.

> "We will collect data to better understand the environment and environmental challenges in the deep sea and find out how exploration can be done efficiently and with the least possible environmental impact."

Last autumn, the Ministry of Petroleum and Energy published an impact assessment. Following a consultation process, a parliamentary proposal on the opening of the Norwegian continental shelf for mineral activities will be submitted this spring.

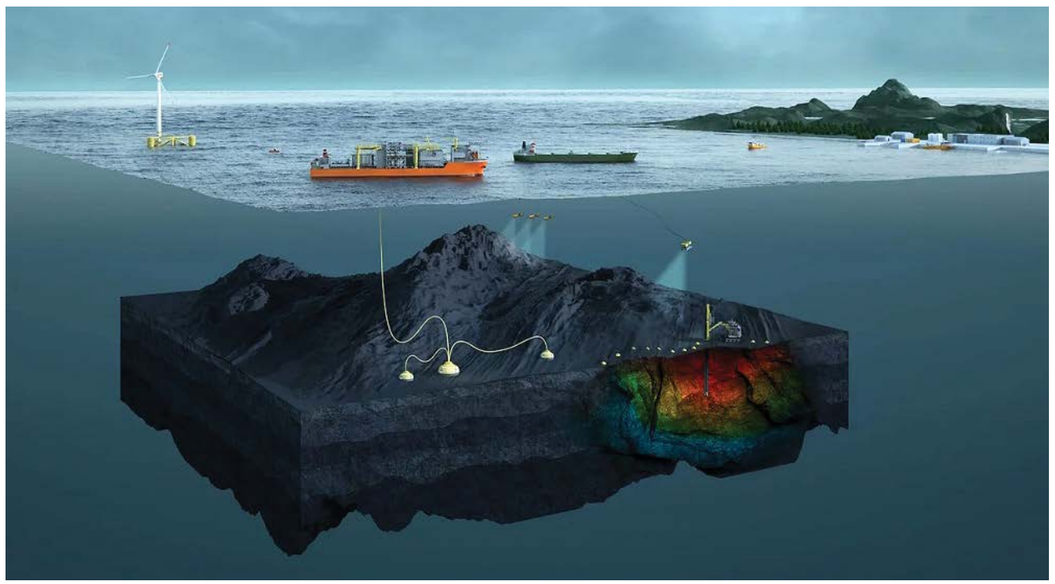


ILLUSTRATION: EMINENT

PHOTOGRAPHY: ANETTE TVEDT; HALFDAN CARSTENS

DEEP INSIGHT

The EMINENT project's tasks are divided into four areas: environment, exploration, extraction and processing. The project participants will develop and demonstrate new technologies for exploration as well as ways to develop technology for extraction and concepts for the entire value chain.

The participants will set out on their first research trip this spring. The expedition is called **Deep Insight** and will be led by the University of Bergen.

"We will collect data to better understand the environment and environmental challenges in the deep sea and find out how exploration can be done efficiently and with the least possible environmental impact. The data we obtain may also be useful in connection with possible future extraction and processing", said Anette during her talk.

The cruise participants will also test new equipment related to both environmental monitoring and exploration.

"We will make maximum use of the cruise days and equip the platforms with as many sensors as possible to collect as much data as possible."

Among the questions and issues the cruise participants want to become wiser about are the environmental state of the deep sea, where they can potentially extract minerals in the future, what environmental impact exploration activities can have, how deep sea minerals can be extracted with minimal environmental impact, how the ore can be processed and geological questions such as how the hydrothermal the systems have been formed.

It is the inactive hydrothermal systems that will be relevant for extraction, and then it is important to understand their formation.

Besides Adepth Minerals, EMINENT consists of UiB, NTNU, UiT Norway's Arctic University, NORCE, Future Materials Norwegian Catapult Centre, Akvaplan Niva, NOV, Aanderaa, DeepOcean, Shearwater, Aker BP, Seabed Solutions, Geoprovider and GCE Ocean Technology. ■

An industry insider for more than 40 years

Jane Whaley looks back at her years as editor of the magazine.

Jane Whaley, editor for GEO EXPRO from 2010 to 2020.

"I STARTED MY CAREER in 1977 as a geologist with Decca Survey, working offshore on shallow, high-resolution seismic surveys; I was always the only woman on board and I think I was the first female geologist to work on seismic boats in the North Sea", says Jane Whaley, former editor of GEO EXPRO magazine.

Surveying, seismic interpretation and geological data analysis remained the backbone of Jane's career until 2004. It brought her to the Middle East, Gulf of Mexico and Ireland before she returned to the UK for IHS. "When our group at IHS was made redundant, it was time to do something new", Jane adds.

"I met the GEO EXPRO team at Petex in November 2004, not long after the magazine had been launched. I was looking for something new and interesting and approached the team on the stand. I liked the look of the product, with a broad range of topics and good quality illustrations, so was very pleased when Halfdan Carstens followed up the meeting by asking me to write a profile of well-known geologist Dick Selley – who turned out to be a dream-interviewee for a rookie magazine writer! For the next six years, I was associate editor for the EMEA region with the magazine, writing a number of articles on a variety of topics for each edition."

"When I took on the role of editor in 2010, I did not feel there was anything I urgently needed to change, as I inherited an excellent format from Halfdan. The thing I really concentrated on was maintaining and building an international focus, as the magazine sometimes had too much of a NW Europe flavour at times."

RESISTANCE

"When I started as editor in 2010, there was resistance in the industry to the growth of sustainable energy solutions and we were worried that including discussions on the implications of climate change would be unpopular with readers or advertisers", continues Jane.

"That attitude changed as people realised that the energy transition was an opportunity, not an existential threat, and I was able to include more articles on the topic and on the openings available for geoscientists in the new energy world."

> "I tried hard to add diversity to the magazine, as the industry is often seen as 'male and pale."

CONFERENCES

"Attending conferences was vital and it enabled me both to source material from around the world and to keep up to date with the latest technical developments. I scrutinised programmes for interesting content and attended talks on the exhibition floor, but many fascinating articles came simply from talking to people at our stand.

"I also tried hard to add diversity to the magazine, as the industry is often seen as 'male and pale'."

HERE'S TO THE NEXT 20!

"I am very happy to see the magazine continue with such great, wide-ranging content and up-to-the-minute technical coverage for geologists throughout the entire energy industry. There are still lots of fine illustrations and great covers, though maybe not as many maps as I would like and I do miss a regular geotourism for a bit of armchair travel", concludes Jane.

"And, I have to admit, I'm not so keen on the brown theme throughout. But I am still immensely proud of this magazine and the contributions I made over its first 20 volumes. Congratulations to the team and here's to the next 20!" ■

HOT SPOT

Bid rounds in the Middle East and South Asia – the shop front is open

Madeleine Slatford
Madeleine.Slatford@nventures.co.uk

While companies consider their path toward net zero, opportunities remain for the shrewd explorer to target low-cost, low to medium-risk exploration in proven and emerging basins, not least across the often overlooked Middle East and South Asia regions, writes Madeleine Slatford from NVentures Ltd.

IN MAY 2023, at the time of going to press, the Middle East and South Asia region had eight licensing rounds open, with three more offshore rounds anticipated during the year. Such a vast tract of acreage on the table - approximately 560,000 km² - has surely something to offer to companies still keen for exploration. Cross-border geological data and trends can also be harnessed by reviewing bid rounds in adjacent nations, such as Lebanon, Israel, Pakistan and India.

LEVANT

In the Eastern Mediterranean, the Levant Basin is a well-established gas province with Early Miocene Nile Delta-derived sandstones characterised by good reservoir properties. Lebanon and Israel are both offering offshore acreage in bid rounds due to close 30th June 2023. Recently acquired and reprocessed multi-client 2D and 3D seismic data is available to evaluate the acreage, comprising 20 blocks offshore Israel, and eight blocks offshore Lebanon. The pending Qana-1 well to be drilled by TotalEnergies and partners in Lebanon's southerly Block 9, adjacent to the now ratified maritime boundary with Israel, will no doubt raise interest in the adjacent acreage.

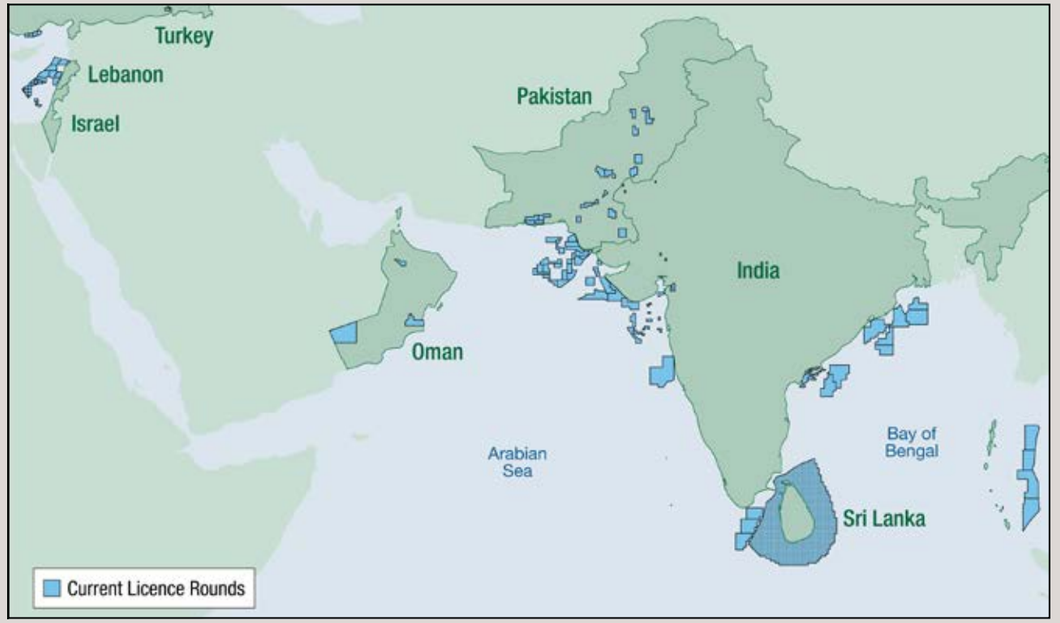
OMAN

Moving east, three blocks are on offer onshore Oman until 25th June 2023, with an offshore round scheduled to open later in 2023. Both conventional and unconventional plays may be targeted in Oman's onshore, a mature petroleum province with good infrastructure and legislative framework. Data can be viewed through an online portal.

While details are not yet released on Oman's offshore acreage to be offered, this area has been highlighted in recent years with high-quality reprocessed seismic revealing toe thrust structures and DHI-supported targets in the Arabian Sea. ENI are due to drill a second deepwater offshore well later in 2023. The UAE too is expected to offer acreage in various Emirates.

Will these fishermen from Sri Lanka soon be joined by people hunting for deeper riches?

PHOTOGRAPHY: STEFANO ALEMANI/UNSPLASH



MAP: NVENTURES

SUB-DECCAN PROSPECTIVITY IN PAKISTAN

Pakistan is also due to offer offshore acreage in the second half of 2023, with the block outlines already defined. While there has been no significant exploration success in the offshore Indus Basin, it is poorly explored, with the Upper Cretaceous Deccan basalts traditionally viewed as economic basement.

Deeper Cretaceous plays productive in the onshore Lower Indus Basin may nonetheless be viable, and a discovery reported in the data packages for the Saurashtra Basin of India, on trend to the south-east, indicates sub-Deccan plays can have some success.

Deeper Cretaceous plays productive in the onshore Lower Indus Basin may nonetheless be viable, and a discovery reported in the data packages for the Saurashtra Basin of India, on trend to the south-east, indicates sub-Deccan plays can have some success.

NOT THE DESIRED INTEREST

India currently has two bid rounds open, OALP VIII and IX. Repeated extensions to the bid deadline for the OALP VIII indicates that this round has perhaps not generated the desired interest. Reports that international majors such as ExxonMobil and Shell may partner NOCs in emerging basins such as the Andaman, contiguous with the Timpan discovery in offshore Sumatra, could provide a boost to an exploration scene that has been dominated by domestic companies in recent years.

SMALL COUNTRIES – BIG OPPORTUNITIES?

Sri Lanka, meanwhile, has reset its petroleum legislation and block definition in the hope of attracting new investment. The 15 x 15 km graticule system, while allowing the bidder freedom of selection, will need to be carefully managed to ensure bidders receive the running room necessary for a frontier setting.

While not yet announced, Bangladesh intends to open a round this year. With new seismic data in the Bay of Bengal to support it and some interesting well results reported by Gazprom between August 2022 and April 2023, the country should probably attract some interest. However, timing is everything and Bangladesh will have to be careful not to be left behind in encouraging exploration interest and investment. ■

Madeleine Slatford, NVentures Ltd

NOTHING BEATS THE FIELD

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.

An analogue for Ephesus?

AS DESCRIBED in the cover story of this magazine, BP is drilling or has just completed the Ephesus or Cape Creel exploration well off the northeast coast of Canada. The main target of the well is an Eocene deep-water sandstone, which formed the main reason for us to feature an outcrop of an equivalent sandstone here.

This photo, kindly provided by Roy Luck from Apex Subsurface in Houston, shows the Skoorsteen Formation in South Africa's Karoo Basin in the Western Cape Province. The outcrops in this Permo-Triassic foreland basin are famous for analogs of channelised turbidites or basin floor fans. The section shown here displays part of the Tanqua submarine fan complex. A prominent sandstone can be seen in the upper part of the outcrop, which is interpreted as a turbidite channel, looking across the channel axis. Below the channel, basinal mudstones with some thin intercalated sandy mass flow units can also be observed.

Photography: Roy Luck

Leslie Kimberlite core

How only recently Canada became a major exporter of diamonds

BARRETT ELLIOTT, NORTHWEST TERRITORIES GEOLOGICAL SURVEY

THE HISTORY OF DIAMOND exploration in the Northwest Territories began in 1981 with Charles Fipke and Stewart Blusson sampling the Mountain Diatreme in the Mackenzie Mountains. While this prospect did not pan out for diamonds, they then collected till samples in the Blackwater Lake area and recovered kimberlite indicator minerals with compositions consistent with diamond-bearing kimberlite.

By 1990, they had traced these indicator minerals over 600 km to the Lac de Gras area. Chuck Fipke noticed a crater-like lake, where geophysical surveys showed the presence of a pipe-like conductivity anomaly. Subsequent drilling in 1991 intersected a diamond-bearing kimberlite, triggering the largest claim staking rush in Canadian history which covered over 28 million hectares (70 million acres) in the Northwest Territories and Nunavut.

The Northwest Territories (and Canada's) first diamond mine began production in 1998 and the latest opened in 2016.

MILLIONS OF TONNES

The Leslie Kimberlite, which was discovered in 1992 as part of exploration in the Ekati area, has an inferred resource of 16.3 million carats hosted in 50.8 million tonnes with a 7-hectare surface expression. It is made up of mostly dark-grey coherent kimberlite with abundant olivine macrocrysts in a groundmass of olivine micro-phenocrysts, monticellite, calcite and perovskite with minor phlogopite and apatite. Pyrope garnets, chrome diopside and lesser peridotitic xenoliths are found throughout. It is age dated at 53.1 +/- 0.7 million years ago and is thought to have formed by a highly explosive eruption which excavated a carrot-shaped portion of host rock that was subsequently in-filled by a lava lake with an estimated minimum volume of $2.3x10^7$ m^3, which solidified into a mass of coherent kimberlite.

The close-up photo shows the textures typically associated with coherent kimberlite, and is dominated by coarser olivine crystals (medium to pale grey) set in a very fine-grained groundmass. Aside from some of the sub-mm olivine crystals and some small black spinel, it is difficult to identify the other minerals present in the groundmass visually, so optical or scanning electron microscopy is mostly used instead.

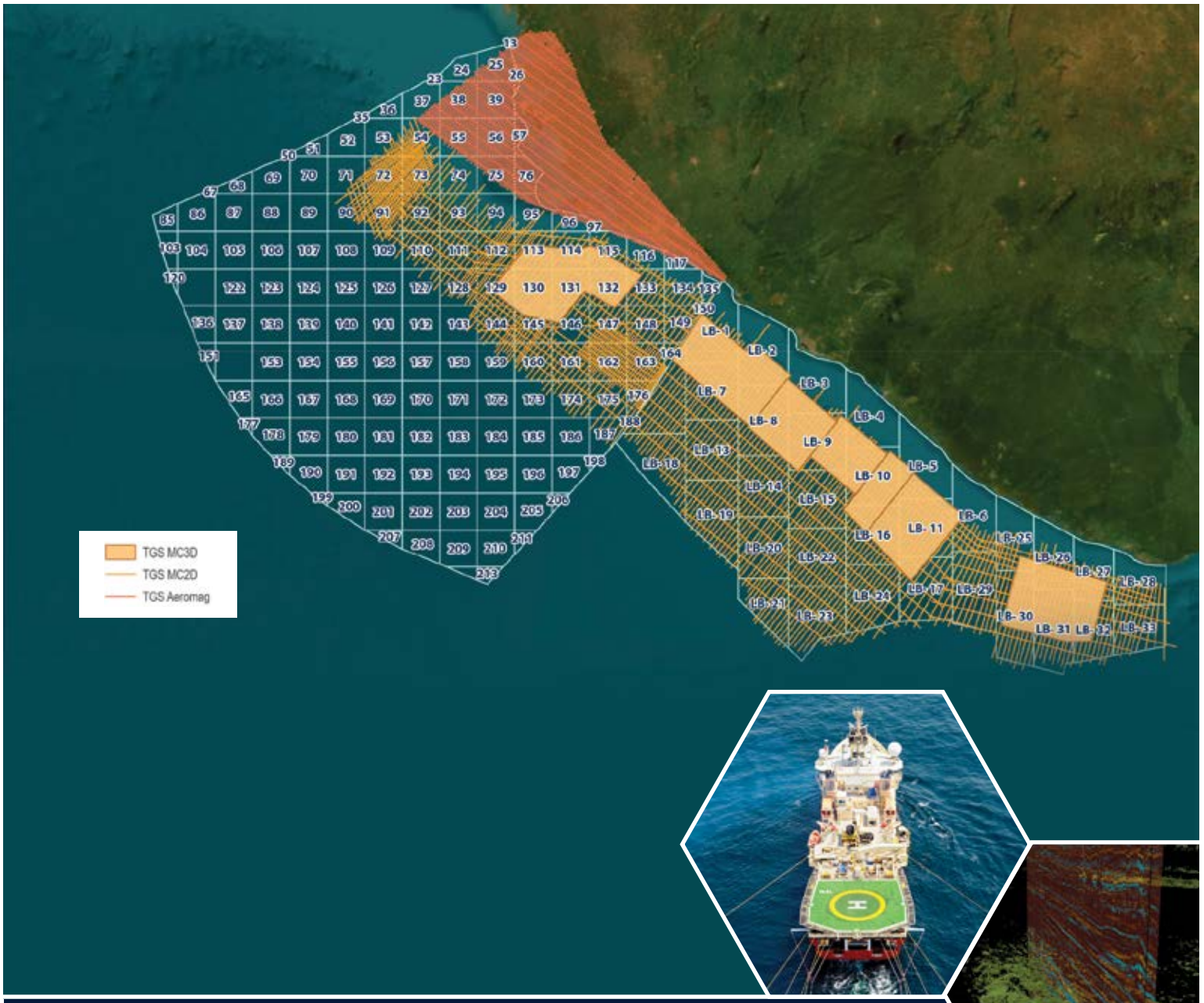
Relatively abundant pale purple pyrope garnet and green chrome diopside are also present, and most have been partially to completely altered to dark brown and medium brown secondary minerals respectively. Some portions of the core are cut by post-emplacement calcite veining. ■

This core is part of the Government of the Northwest Territories drill core collection. The Geological Materials Storage Facility in Yellowknife, Northwest Territories houses well over 50 kilometers of mineral exploration core, and strives to obtain representative drill core from most drilled NWT mineral deposits. The core is available to companies and researchers for examination and testing.

More information at:
www.nwtgeoscience.ca

Leslie Kimberlite.

PHOTO: BARRETT ELLIOTT



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