Supporting global exploration trends with geoscience insight

Erling Frantzen[1]*, Anna Lougon[1] and Joe Zhou[1] discuss how advanced geoscience technologies and data are successfully supporting the search for hidden opportunities in the world's hotspots.

There has been something of a return to frontier exploration in the past few years, with several key energy players recently announcing a change in direction towards increasing their oil and gas reserves to ensure the world's future energy needs are met.

This trend will have an impact not only on countries and regions that have seen little recent exploration activity but also on the industry, which will need the support of high-end geoscience technologies, data and expertise to better understand prospectivity, reduce risk and increase the success rate of future exploration initiatives.

Geoscience technology companies (GTCs) play an integral part in the exploration process by applying their in-depth geological knowledge and high-end imaging technologies to offer timely multi-client earth data projects. These provide energy companies with the best possible and most accurate subsurface seismic images, helping them to reduce uncertainties and interpret and understand new plays.

This article summarises the extent of the critical role GTCs play in supporting energy companies in the search for hidden opportunities in the world's hotspots.

Strong partnerships drive resource development

An often-overlooked key driver of successful multi-client surveys supporting new resource development is the nurturing of good, long-term relations between GTCs and governments/authorities, national/international oil companies (NOC/IOCs) to ensure the right regulatory, fiscal and environmental framework and other appropriate local conditions are in place to deliver positive outcomes. Such relationships can take years or even decades of commitment; rather than drift in and out of a country as industry activity waxes and wanes, it is better to fully support governments as they work to meet these energy challenges.

To develop a successful partnership, it is important that a GTC understands the culture and needs of a country and its relevant agencies. While it will bring best practices, gained through many years of in-depth experience working in different settings around the world, to a frontier area in both the technological and environmental arenas, the GTC will also benefit from decades of experience and regional knowledge available within the ministries and NOCs. The relationship needs to be positive for all parties, so that everyone feels comfortable and confident about the undertaking, working together to realise a country or region's energy potential.

The importance of a stable regulatory environment is not just relevant to frontier exploration areas. Norway, for example, has continued to be a 'hotspot' in the industry for many years, with regular licensing rounds, a transparent and predictable fiscal regime and supportive authorities, making it easy for both oil companies and technology experts to invest in the area. However, if regulations change over relatively short periods of time, as has happened recently in the UK and the US Gulf, it can upset the stability needed for successful operations.

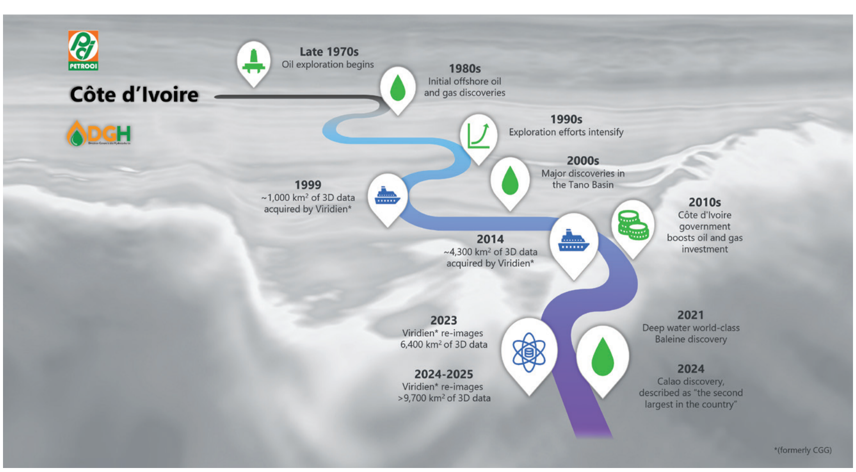

Figure 1 Example of a Viridien long-term partnership, through data acquisition and imaging projects with Côte d'Ivoire's Direction Générale des Hydrocarbures (DGH) and PETROCI Holding (PETROCI).

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DOI: 10.3997/1365-2397.fb2025038

The energy industry is based on effective relationships, not just with governments and authorities, but also between key industry players. GTCs often team up with each other, as well as with oil and gas companies or with several partners, to share knowledge and develop innovative methodologies and projects to address industry trends.

Advanced technology unlocks the subsurface

It is important that the industry continues to develop innovative techniques that can help derisk new plays. One challenge is to incrementally improve high-end seismic imaging, to deliver the most accurate images of the Earth's subsurface, thereby delineating geological structures which will help to reduce uncertainties and reveal previously undiscovered resources.

In the past decade, the most important imaging technology development is Full-Waveform Inversion (FWI). This technology, aided by FWI-friendly acquisition design (long offsets and low frequencies), is particularly effective for imaging beneath the salt and has been successfully utilised in the US Gulf as well as many other locations with a complex overburden.

Although it is only about ten years since it was widely used in seismic projects enabled by exponentially growing computing power, FWI has continued evolving and maturing. One advancement is Time-lag FWI, which minimises FWI cycle-skipping issues and is used for delineating very complex geology, including sub-salt, carbonates and thrust belts. A further enhancement to this technology is elastic-FWI. This combines an elastic modelling engine with the time-lag cost

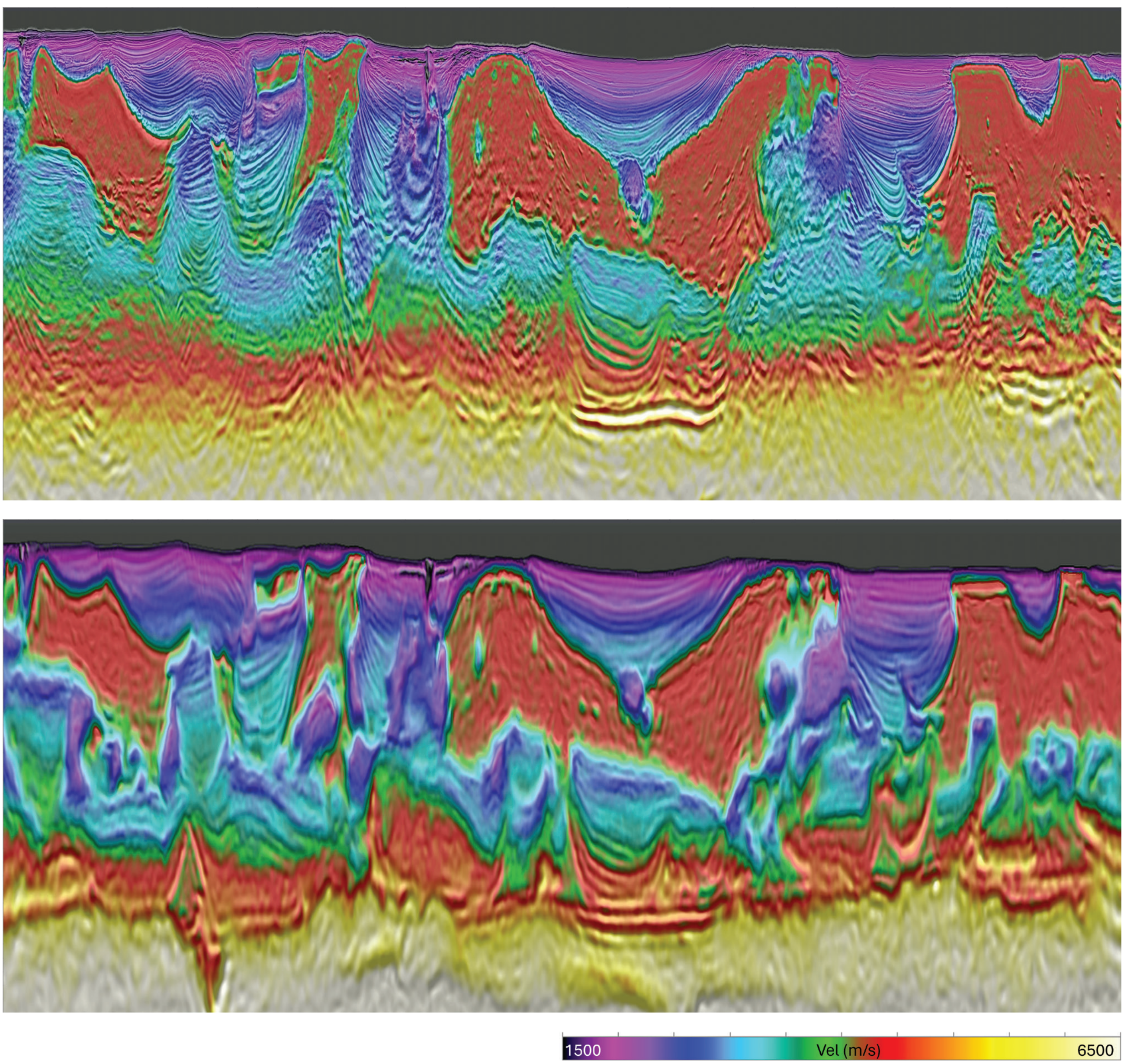

Figure 2 Laconia in the Garden Banks area of the US Gulf: Streamer 15 Hz RTM image overlaid with 6 Hz Streamer AFWI velocity (top) and OBN early-out 5 Hz AFWI Image overlaid with corresponding velocity (bottom). The early-out OBN FWI provides a significantly improved image of the deep basin architecture. Of immediate significance are the updates to the imaging of the salt, the recognition of low-velocity shales, and the impact on the imaging of minibasins and salt welds. The imaging of deep structural features, including autochthonous salt and the pre-salt basement, are also significantly enhanced (courtesy of Viridien Earth Data).

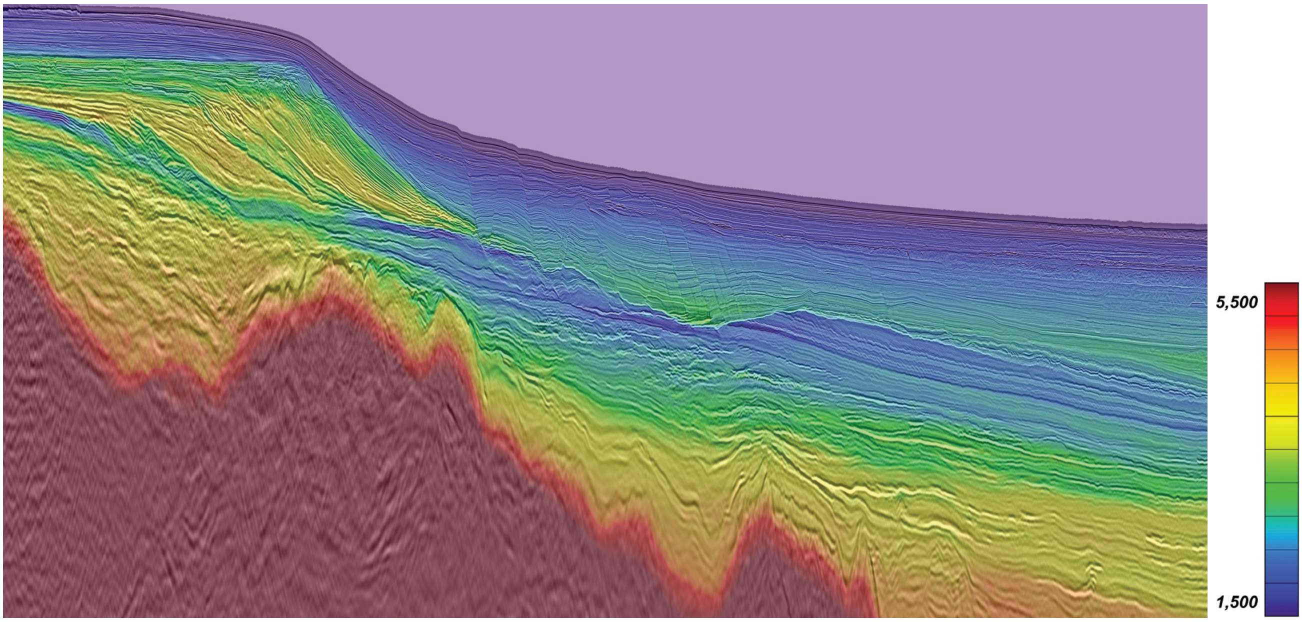

Figure 3 Seismic section from the Amapa Basin, offshore Brazil, with an overlay of the FWI velocity model. The model effectively characterises the Amapá carbonates on the shelf and at the shelf break, while also distinguishing different stratigraphic intervals. The improved imaging beneath the thick carbonate interval even allows for the identification of new prospects (courtesy of Viridien Earth Data and TGS).

function, with benefits such as a reduced salt halo, sharpened salt boundaries and better structural continuity.

FWI technology relies on a clear low-frequency component in the recorded data, so for the highest quality results a good low-frequency marine seismic source such as the Sercel TPS™ (Tuned Pulse Source) is ideal. An innovative broadband source like this can help to improve images in complex areas such as sub-salt or sub-basalt and has the added advantage of being more environmentally friendly than conventional airgun sources, as the low frequencies minimise impact on marine life.

Advanced imaging techniques also help to maximise value extraction from legacy data. Reimaging years later provides excellent resolution and significant uplift in image quality, and in some cases has led operators to fundamentally change their ideas on the reservoir model. Moreover, this approach promotes sustainability by maximising the use of existing data and minimising the need for new acquisitions, thereby reducing cost and environmental impact.

While FWI technology is still rapidly evolving, its benefits are evident and we expect to see it mature with wider applications and greater impact, which could well lead to success in regions that have so far been unproductive.

In addition, AI and machine learning (ML) are beginning to transform new seismic imaging, shifting from manual processes to AI-driven models that generate subsurface insights rapidly, freeing experts to focus more on high-end analysis. As these technologies evolve, they demand greater compute power for advanced data handling, making it crucial for the industry to invest in both cutting-edge innovation and a skilled workforce to sustain future exploration and discovery.

Seabed nodes and FWI

Returning to acquisition innovations, one of the most exciting technologies of recent years is the wider-scale deployment of long-offset low-frequency ocean bottom node acquisition (LOLF OBN), where receivers are placed on the seabed instead of being towed in streamers behind a vessel. The use of sparse OBNs and a low-frequency source, which gives extra-long offset and rich low frequency, allows for deep diving wave penetration which maximises FWI's power in sub-salt velocity updating and imaging.

Our recently completed Laconia acquisition in the Garden Banks area of the US Gulf in water depths of more than 2000 m is the largest ever low-frequency sparse OBN survey. The early-out 5 Hz Acoustic FWI imaging results are said to have completely revolutionised thinking about petroleum systems in the Gulf and possibly identified plays down to basement level. The survey used nodes spread over 8000 km^2, a source coverage of over 19000 km^2, and deployed five vessels and about 300 people at the peak of the survey. One of the main challenges facing the use of this technology, therefore, is how to bring its cost down.

In fact, the cost of OBN, particularly in deep water, has limited the use of OBN to field development in places like Brazil, even though the technology would be ideal for exploration, to delineate that region's complex pre-salt geology. At present, in Brazil, exploration of the subsalt has been enhanced using long-offset seismic combined with FWI processing of both new and legacy data.

There has also been a shift in recent years from streamer to OBN acquisition to obtain better images in more mature exploration areas. Viridien, for example, has invested in OBN surveys for near-field exploration in Norway, both because towing a long streamer around a production area is not feasible and because OBN acquisition and imaging allows for better illumination potential of subtle and small prospects. It does, however, impose the logistical and operational issues of a node-laying and recovery operation, and has cost implications.

Looking ahead, in proven global hotspots the number of OBN surveys are expected to increase while new streamer acquisition

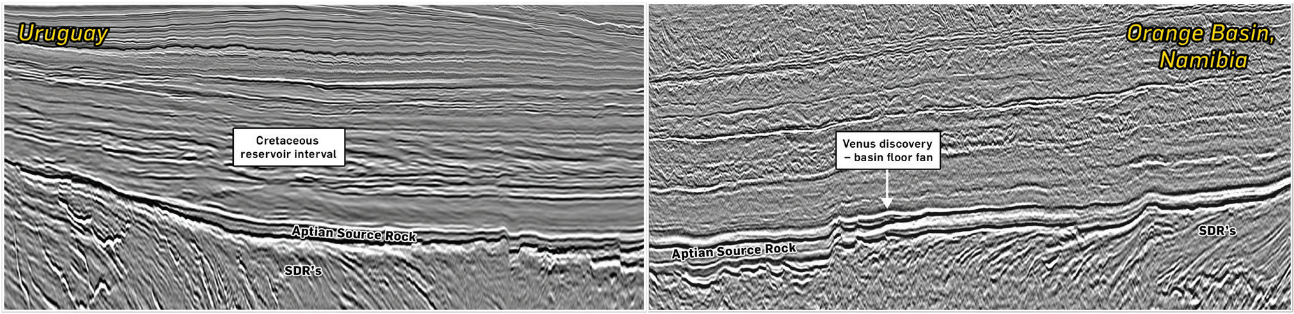

Figure 4 A comparison between the conjugate margin of Uruguay (left, courtesy of Viridien Earth Data) using newly completed 2024 3D PSDM reimaging and Orange Basin, Namibia (right, courtesy of NAMCOR, Viridien Earth Data & TGS) using 2D PSTM (2018) reimaging, highlighting similarities across the margin in terms of structural evolution, basin geology and hydrocarbon potential.

will decrease in volume, but there will also be a movement towards hybrid acquisition.

Exploration trends in the Americas

Offshore Americas, exploration is moving into deep and ultra-deep waters, with increasing interest in the equatorial margin of South America and into the Caribbean, as well as the US Gulf. While many giant fields have been found, companies are still keen to make large new discoveries, driven by the use of modern technologies, both in data acquisition and imaging.

The US Gulf is traditionally thought of as a mature exploration area, but focus is now moving from the well-explored shallower Miocene to the complex geology of the deeper Paleogene intervals. With improvements in seismic imaging technologies such as FWI, it is now possible to image these deep layers, and although little exploration has been undertaken in these intervals in the last few years, there is a growing interest in exploring the deep geology of the Gulf.

Similarly, interest all along the southern Atlantic margin has been increasing and this trend is expected to continue. Uruguay, for example, received little attention until recently. However, after discoveries in Namibia's Orange Basin raised industry expectations that a similar success could be replicated in its Conjugate Margin, Uruguay now has 100% of its acreage under licence. Viridien's recently completed reimaging of 25,000 km^2 of its offshore legacy seismic 3D data – using advanced imaging technologies such as TL-FWI, to enhance the existing data – provides previously unseen details of the country's deepwater formations. Adjacent to Uruguay, the Brazilian Pelotas Basin could well be the next exciting region to open up for that country, encouraged by discoveries in the conjugate margin in Namibia. Viridien started acquiring the first seismic data there more than 10 years ago and there is a lot of interest in the area. In fact, discoveries in Brazil and Guyana have encouraged exploration throughout the Atlantic margin, from Argentina and Brazil to Suriname and Trinidad, even in countries like Aruba, where we are undertaking new 2D reimaging (PSTM) focused on the Western Curaçao Basin, and Curacao that have received little interest until now. Meanwhile, in Brazil, the pre-salt remains prolific and promising, and companies continue to look for new prosects and plays.

Two exciting deepwater discoveries last year have generated interest in the Potiguar Basin in north-east Brazil, continuing the trend from Guyana and Suriname. The latest imaging technologies have been used to achieve substantial improvements in both pre- and post-salt images, which can potentially help to drive further activity in these regions.

Successfully exploring these relatively new territories is aided by large libraries of legacy 3D seismic data, which are being reimaged with the most recent methodologies, including FWI and TL-FWI. These innovative technologies are allowing companies to image the geology more accurately, to go deeper into the formations and ultimately to derisk their prospects.

Africa and Europe exploration trends

Frontier exploration is on the rise again in Africa, with deep-water Namibia garnering considerable attention after several discoveries in recent years. In this region, application of the latest imaging FWI technologies has revealed new opportunities that had not been evident with original data, increasing interest in the country.

Cote d'Ivoire is also creating excitement after a couple of significant recent discoveries and production has already started from its 2021 Baleine discovery. Promising geology and good government support make it an attractive destination for energy companies and a number of them are looking to enter the country. Exploration will be aided by both re-imaged legacy data and newly acquired multi-client seismic data, which has opened up new opportunities that were not previously visible on the legacy data.

Viridien's PSDM reimaging of more than 6400 km^2 of seismic data has generated new insights and uncovered further prospectivity within the new carbonate and proven clastic plays on the Ivorian side of the Tano Basin. Building on this, and, in collaboration with Côte d'Ivoire's DGH and PETROCI, two new multi-client 3D reimaging programs, CDI24 and CDI25, have been launched. The merging of all three programs creates a seamless and contiguous volume of more than 16,000 km^2, providing a comprehensive and unified dataset crucial for optimising exploration and development efforts in the region.

Application of the latest seismic imaging technologies has also achieved some substantial improvements in the imaging of the pre-salt of Angola, which is likely to help to drive further activity there.

There is also a growing interest in near-field exploration, particularly in Europe. Finding smaller fields that can prolong the life of ageing infrastructure has been hugely enhanced by the application of new technologies such as OBN, particularly where towing a long streamer in an area crowded with rigs, platforms and servicing vessels is not practical.

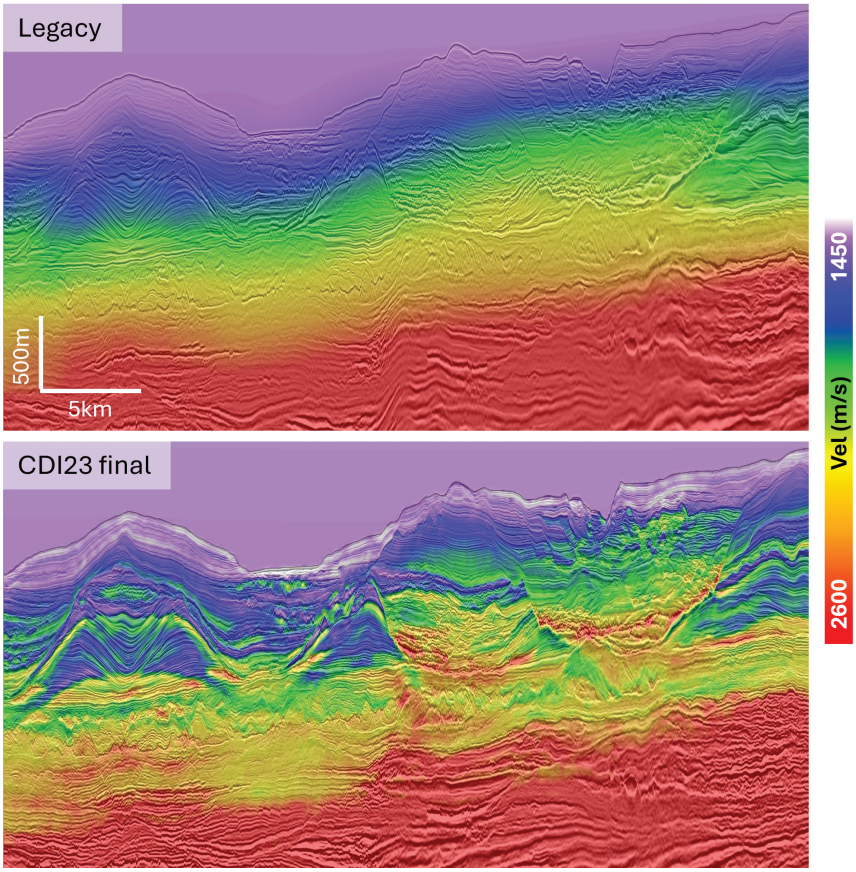

Figure 5 Final data results from the continuing CDI23 reimaging project reveal improved imaging of the syn-transform and post-transform plays, along with higher resolution, thanks to the application of deghosting, demultiple, and time-lag FWI (courtesy of Viridien Earth Data, DGH and PETROCI).

The gradual improvement in seismic data quality has significantly aided the derisking of prospects in the busiest exploration hotspot of the Norwegian Continental Shelf (NCS). In the Northern North Sea, our company acquired more than 36,000 km² of new broadband data from 2014 to 2016, leading to numerous discoveries. Between 2017 and 2024, 21 potential economic discoveries were made. Over the past decade, Viridien acquired 53,700 km² of 3D data, 25,500 km² of dual-azimuth data, and 3700 km² of dense OBN coverage, resulting in 28 discoveries within its Northern Viking Graben surveys. These advancements have enabled companies to optimise well locations, identify new targets, and ensure the NCS remains a dynamic exploration hotspot.

Sustainable energy future

The skills that have been developed over many years to support exploration of oil and gas are now being used in the field of carbon capture and storage (CCS) and renewable energy sources as the world seeks to reduce its carbon emissions. For example, imaging technologies such as FWI can help to find suitable locations for CO_2 sequestration. Using legacy data, reimaged with a focus on aspects of the geology important for CCS, like an excellent seal, is a very cost-effective way of recognising potential carbon storage sites. This advanced processing can also help to identify other important elements in CCS, such as aquifer porosity and permeability and the existence of faults which could cause leakage.

Multi-client screening studies using reimaged proprietary legacy data combined with public databases have identified key storage sites across the world, including in the US Gulf, the North Sea and the Far East. Reprocessed legacy data is also being used to screen regions in more detail to nominate areas for CCS licences, a much cheaper option than running a new seismic survey. It is also interesting to note that many recently awarded storage licences include a commitment from developers to reprocess legacy seismic data.

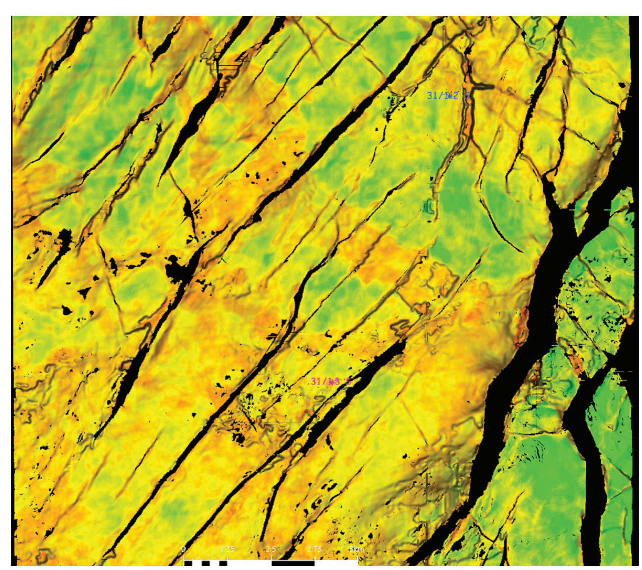

Figure 6 New dual-azimuth imaging using FWI frequencies up to 15hz. This image illustrates the RGB colour-blending of frequencies 10, 20, and 30 Hz from the Brent Group, located west of the Troll field. The areas highlighted in orange have been interpreted as fluvial channel belts, which range in width from 1 to 2 km and cross the main fault trend. (courtesy of Viridien Earth Data).

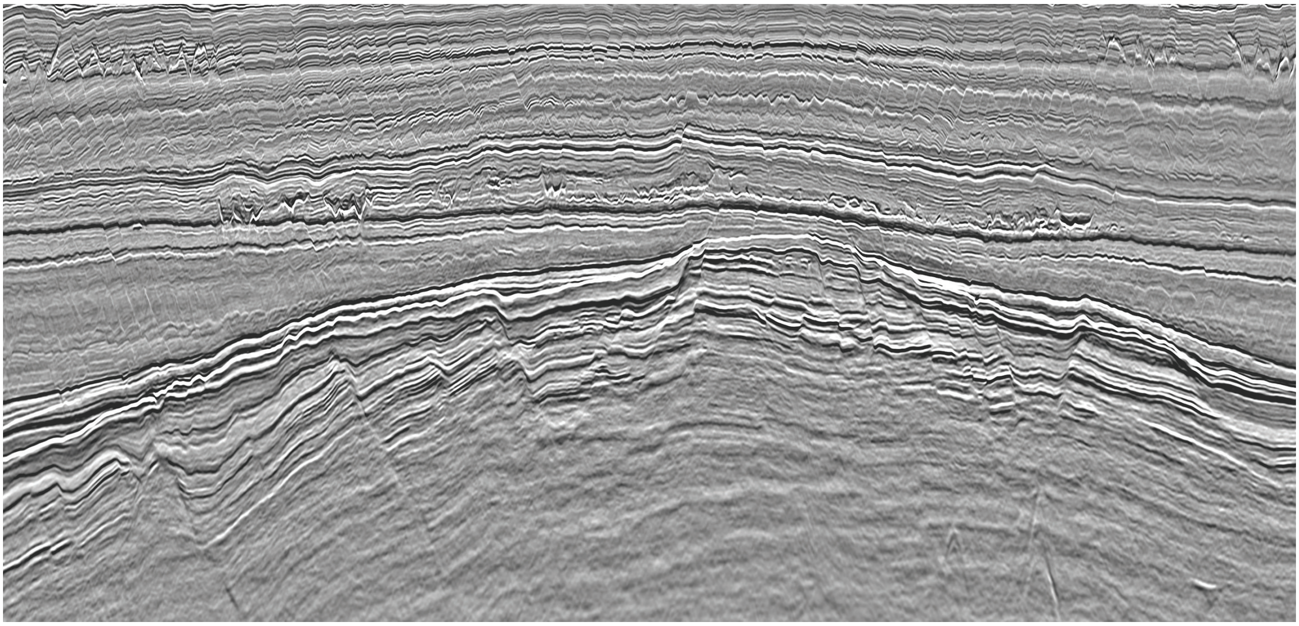

Figure 7 NVG dual-azimuth, oriented north-west to south-east, full stack displaying enhanced image of the deeper Jurassic-rotated fault blocks and the Paleocene injectites (courtesy of Viridien Earth Data).

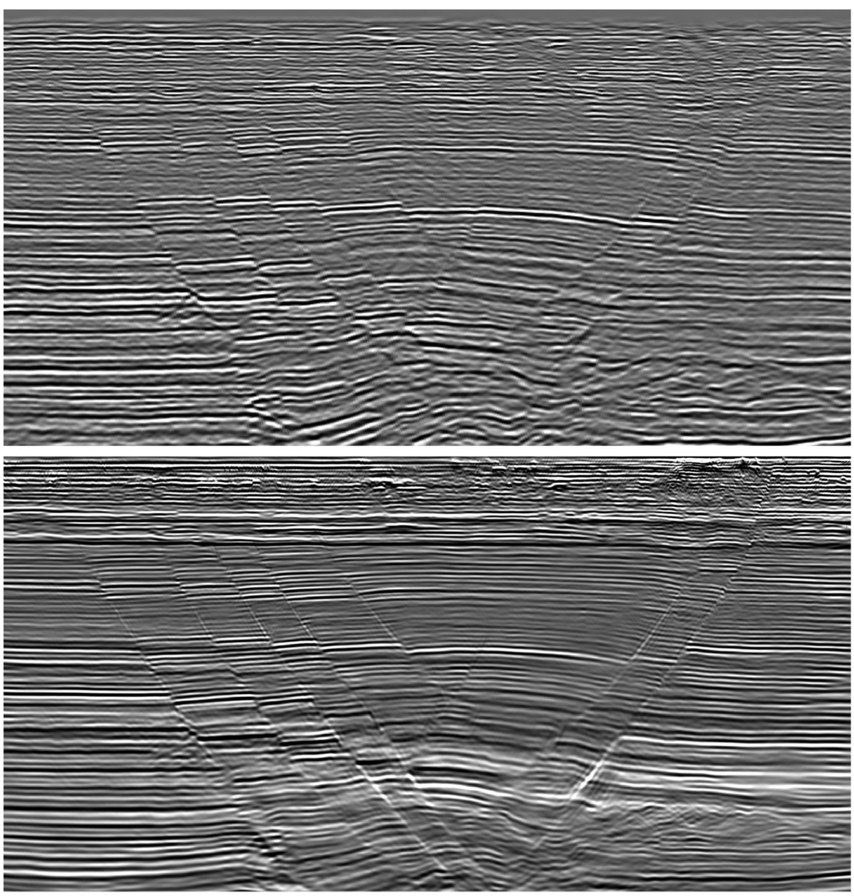

Figure 8 Comparison of legacy seismic and FWI image data based on a reprocessing pilot study in the High Island offshore area of the US Gulf. Improved fault definition in the overburden and potential shallow subsurface hazards helps to better derisk the containment component and build a more accurate 3D model of the subsurface storage complex for carbon storage site characterisation (courtesy of Viridien Subsurface Imaging, data courtesy of Seitel).

As a business that is still in its infancy, carbon capture and storage is going to take time to develop, particularly with respect to the relevant environmental regulations which differ from country to country. It is important that the best possible imaging technology is applied to CCS activity from the beginning to ensure the most accurate results going forward.

Conclusion: future exploration challenges

The industry is changing and while E&P companies are refocusing more towards petroleum, they remain mindful of the world's energy transition challenges. Meanwhile, oil and gas can still provide a key support for a nation's economy; many countries must import 100% of their energy needs and want to achieve energy security and the ability to improve their infrastructure, education and living standards. A variety of energy sources is envisaged in these countries, and the exploration industry should be ready to help them develop their resources in a responsible way.

Committed to a sustainable future, the industry will continue to seek solutions that mitigate its impact and to research methods that reduce its carbon footprint. The success of future exploration will depend strongly on the continuing development of innovative subsurface imaging technologies, such as FWI, TPS and OBN, to ensure the maximum advantage is gained from all data gathered, while efforts continue to reimage existing data that will reveal the hidden resources. These technologies will not only be used to find oil and gas, but will help industries focused on the energy transition, by, for example, identifying sites for carbon sequestration or for offshore wind farms.

While the future holds uncertainties with unpredictable energy markets and potential political instability, the energy industry stands at a pivotal crossroads. The focus must be on providing the energy required now while simultaneously innovating to meet the future's energy needs. By embracing cutting-edge technologies and fostering strong partnerships, the industry can navigate these challenges and drive a sustainable, secure energy future for all.