Uncertainties in upstream oil and gas: The role of integrative technology

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ABSTRACT

In recent years, there has been a noticeable decline in the volume of reserves discovered. This trend can be attributed partly to reduced drilling activity and lower investment, but also to the increasing complexity of exploration. The era of discovering large reserves beneath simple structural traps is largely over. At present, exploration demands a focus on plays with stratigraphic variability, complex geology, and deep targets. This shift necessitates not only advancements in seismic imaging technology, but also a high level of integration and collaboration across disciplines. These themes will be exemplified through a couple of real-world examples discussed in this paper.

Exploration inherently involves uncertainty, whether it is in the presence of source, reservoir, trap or migration pathways. The associated risks can range from dry holes to smaller-than-expected reserves, etc. Seismic interpretation plays a key role in the estimation of exploration uncertainties. Though quantifying uncertainty objectively remains a challenge, certain approaches can meaningfully contribute to exploration success. Drawing from my personal experiences, this paper outlines methodologies that have been instrumental in achieving exploration and development success.

The first example highlights how breakthroughs in near field exploration were achieved by an independent company through integration of geoscience technology with a deep understanding of both local and regional geology. In this case, the geological model of the entrapment was validated by experimenting with and adapting the appropriate seismic imaging and AVO technologies.

The second example emphasizes the value of technological innovation and interdisciplinary collaboration, focusing on the West Delta Deep Marine project. One of the major uncertainties in field development is the connectivity of reservoir channel complexes, which is usually underestimated. The examples shared highlight the role of seismic technology in disentangling different channel systems, and how the integration across disciplines can reduce uncertainty in channel connectivity, which is crucial for infill well planning and reservoir management.

KEYWORDS

Complex geology, uncertainties, seismic imaging, connectivity

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INTRODUCTION

The problem and the need for new approaches

According to Annual Gas Market Report 2024 and Rystad energy (Figure 1), conventional exploration spending has declined, and discovered volumes have reached historically low levels. This trend reflects the industry's shift into new and challenging areas, such as plays with stratigraphic variability, complex geology, deep targets and geopolitically sensitive regions (Dou et al., 2022)

As the upstream business has grown into new and challenging areas, uncertainty has grown significantly. Traditional interpretation techniques and single scenario approaches are insufficient in these areas. Instead, success now depends on the ability to evaluate multiple geological scenarios to play out different ideas, application of cutting-edge technology, and adopt collaboration across disciplines.

FINDING HYDROCARBONS – OPENING A NEW PLAY SEGMENT: A MID-NORWAY CASE STUDY

The block is situated in the Halten Terrace region, offshore Mid-Norway. The generalized stratigraphy of the block is shown in Figure 2. Exploration efforts focused on Upper Jurassic syn-rift plays, with wells drilled to target prospects identified as combined structural-stratigraphic closures with well-defined direct hydrocarbon indicators (DHI's). The main pre-drill uncertainty centered around the entrapment configuration. To address this, the entrapment concept was refined using advanced seismic imaging technologies (Figure 3). In particular, the application of beam depth migration, which offers advantages over conventional Kirchoff migration in imaging complex and steeply dipping structures, proved useful. It provided improved delineation of fault geometries (Notfors et al., 2006), thus validating the entrapment model. The entrapment model was further supported by AVO analysis and fluid factor interpretation (Figure 4), which provided additional confirmation of hydrocarbon presence.

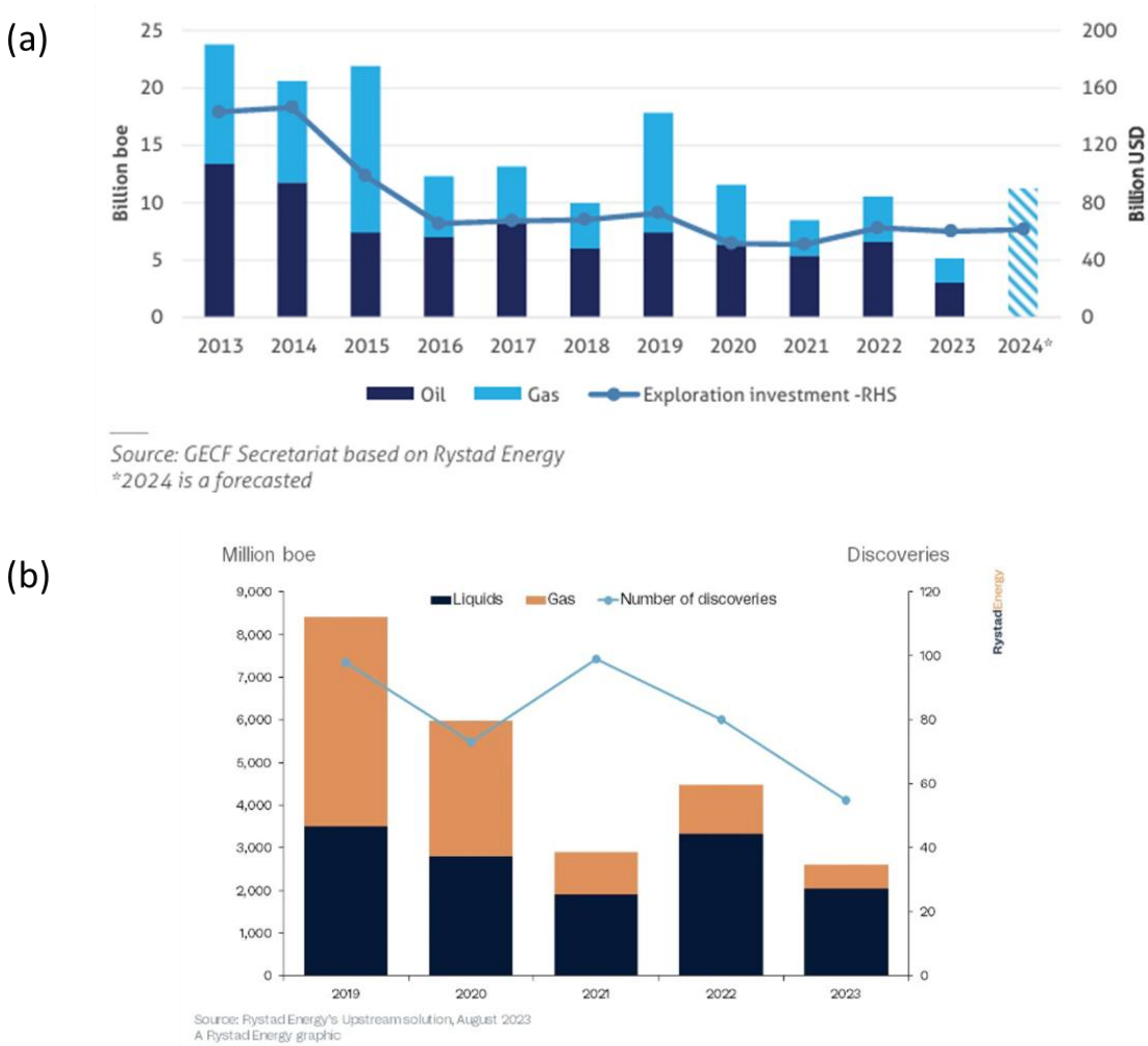


***Figure 1**: Trends in exploration spending and discovered volumes. (a) Global oil and gas volumes discovered vs exploration investment. (Adapted from GECF Annual Gas Market Report, 2024), and (b) Total conventional discoveries by type, January-June. (Adapted from Mahajan, 2023)*

Two wells were subsequently drilled targeting prospects in Upper Jurassic synrift play, both of which encountered commercial quantities of oil and gas. These discoveries diversified the Upper Jurassic play, opening new play segments, novel reservoir types, and new trap configurations.

Interestingly, this block was initially discarded by major operators, who considered it non-prospective. However, significant breakthroughs in near-field exploration were achieved by small, independent oil companies, operating without the benefit of extensive databases or large-scale systemic support. The key differentiators that contributed to success were a deep understanding of the local geology, targeted application of seismic technology, and access to sufficient resources to test and iterate on exploration concepts.

UNCERTAINTY IN PREDICTING CONNECTIVITY FROM SEISMIC: A WEST DELTA DEEP MARINE CASE STUDY

Assessing reservoir connectivity and water resources is key to predicting reservoir performance, particularly in the context of infill development drilling. This study presents a case study from a field in West Delta Deep Marine and highlights the uncertainty in predicting reservoir sand connectivity using seismic data. The seismic data and its attributes were analyzed to identify and map individual channels and their

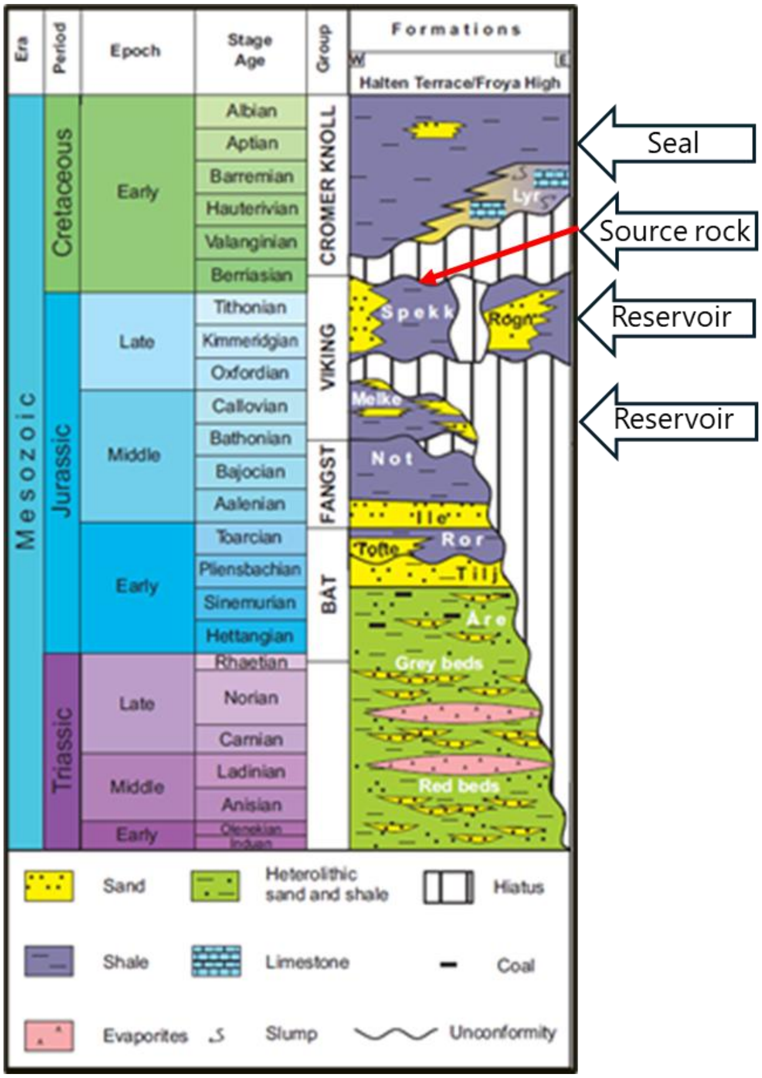
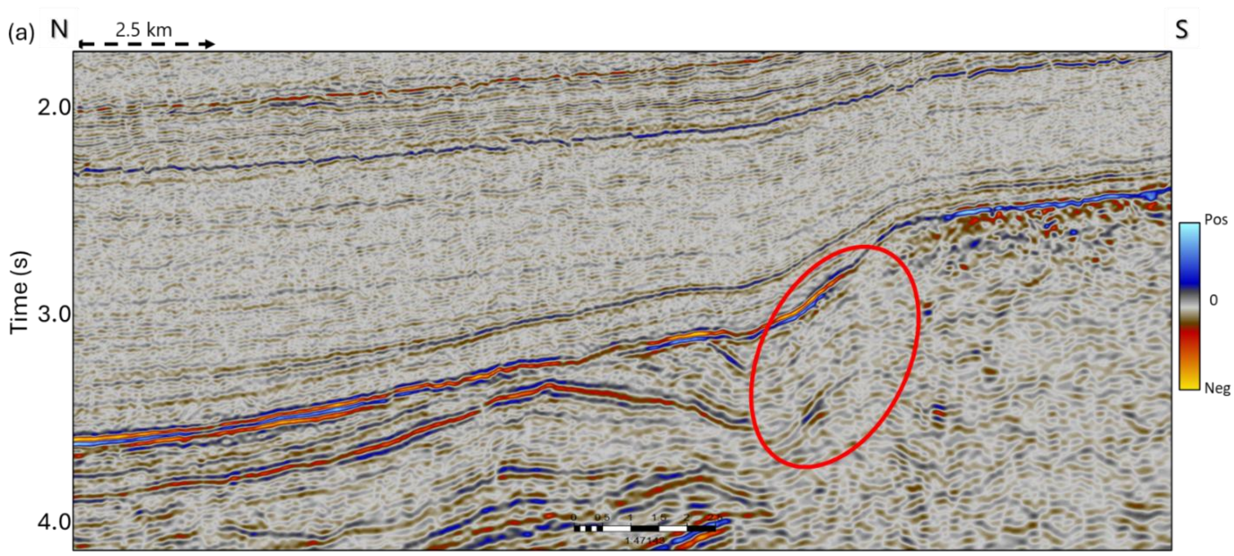


Figure 2: Generalized stratigraphy of Halten Terrace block. The source rock happens to be the Upper Jurassic Spekk Formation, and the reservoirs are found in the Middle/Upper Jurassic Mekke Formation and Upper Jurassic Rogn Formation. The seal is provided by the Upper Jurassic and Lower Cretaceous shale above. (Adapted from Dalland et al., 1988)



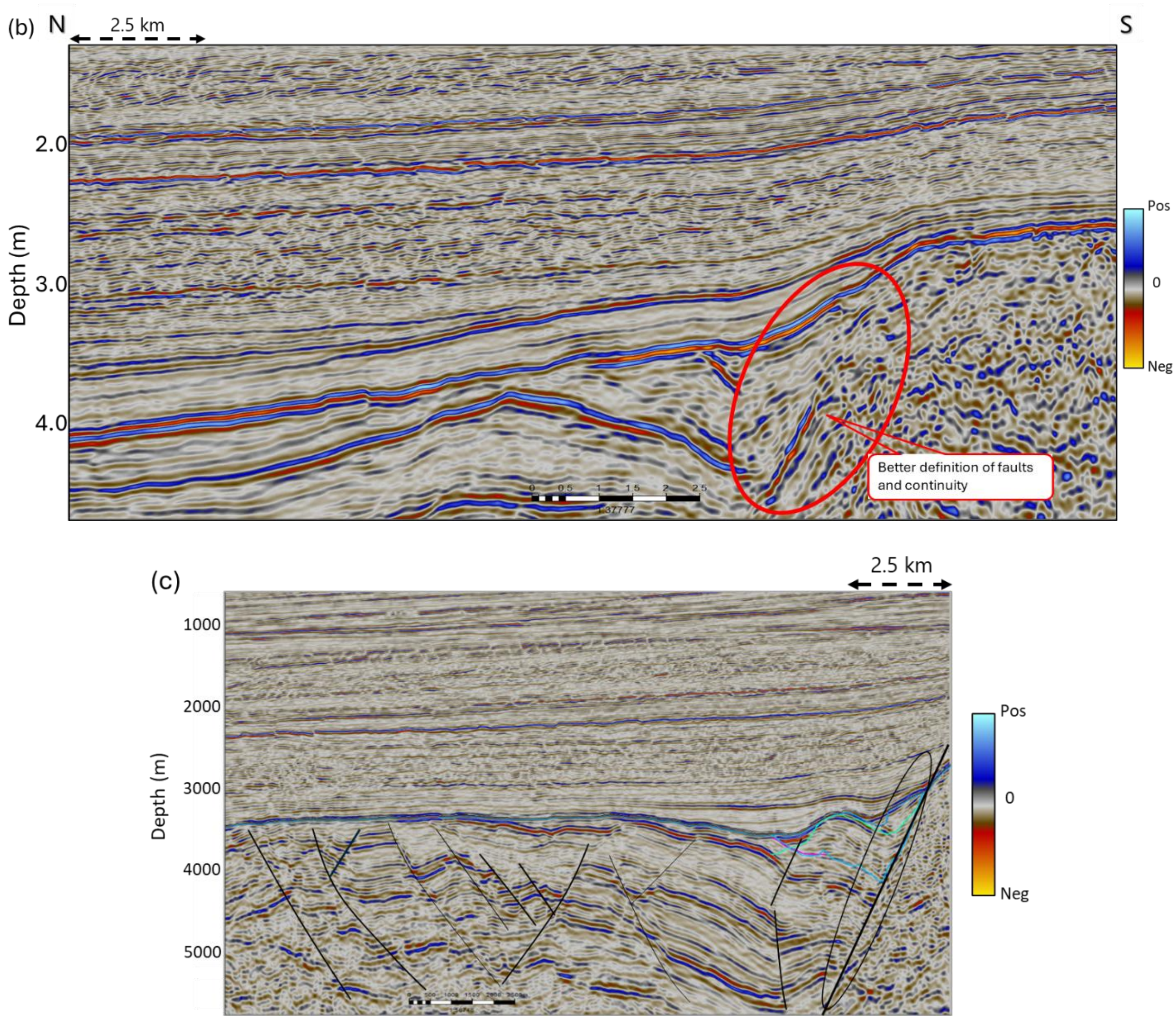
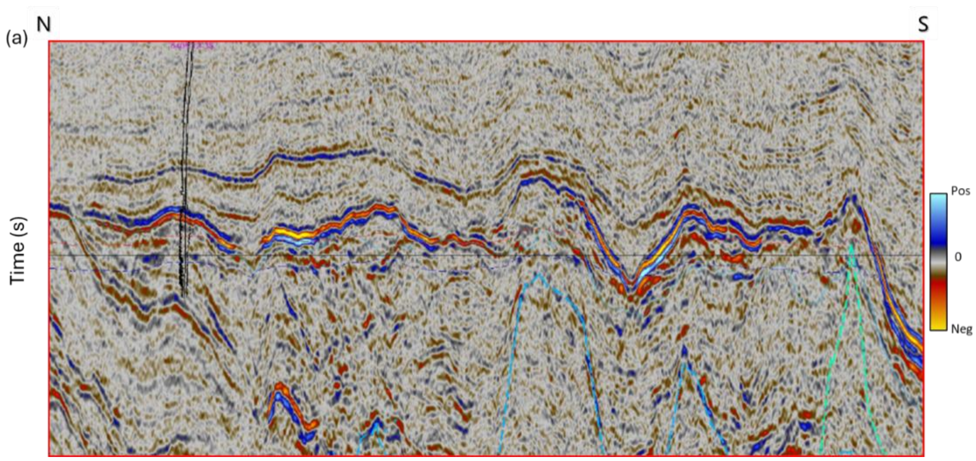
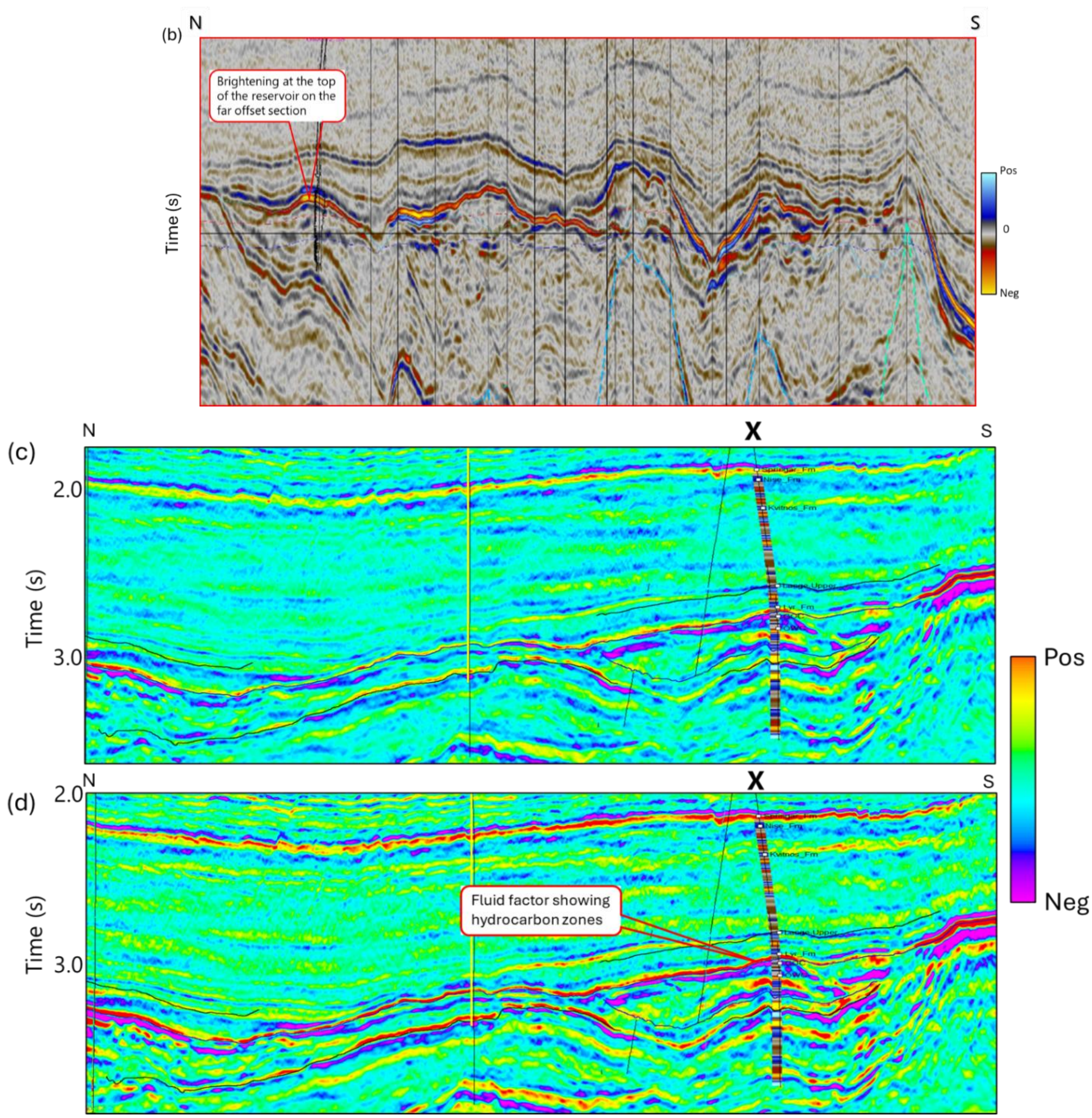


Figure 3: *Comparison of segments of seismic sections from (a) prestack time-migrated, and (b) prestack depth-migrated (beam migration) volumes. The depth migrated data shows better definition of faults and continuity compared to the time migration. A convenient fault delineation geometry is shown on the depth-migrated zoomed section shown in Figure 3c.*





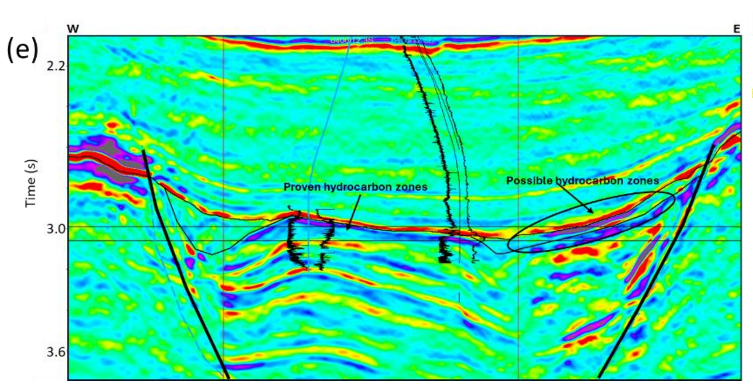


Figure 4: Comparison of segments of seismic sections from (a) near-offset, and (b) far-offset volumes. A brightening of the amplitude is noticed at the top of the reservoir on the far-offset section. A similar comparison segments of sections from fluid-stack volumes generated (c) before drilling of discovery well, and (d) after integrating the result of discovery well. Negative values of fluid stack have been interpreted as presence of fluid stack, which are seen prominently as indicated by the pointer text. (e) A zoomed section from a W-E fluid-stack section shows the proven and possible hydrocarbon zones.

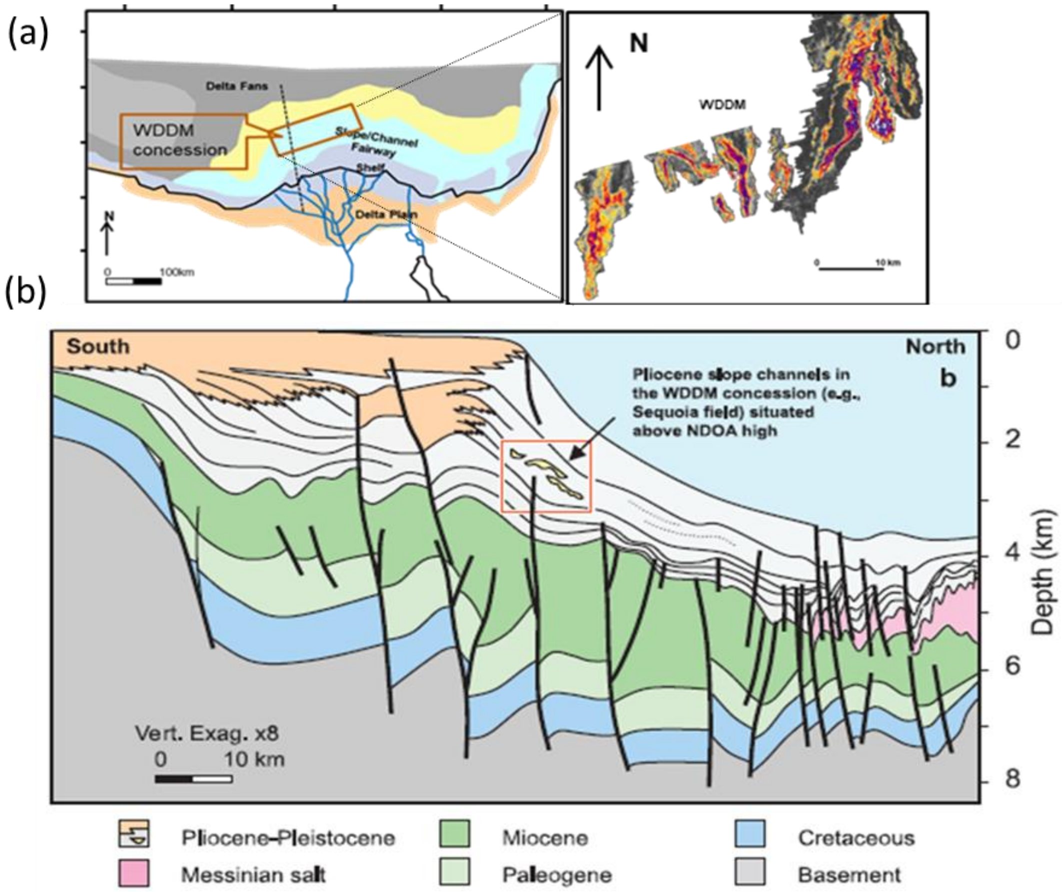


Figure 5: *(a) Location map (left) and seismic amplitude expression (right) of WDDM channels (modified from Samuel et al., 2003). (b) Schematic cross-section (modified from Aal et al., 2006). Many of the gas fields within WDDM are hosted in Pliocene turbidite slope channel systems as seen in Figure 5a. The reservoir architecture is well imaged by 3D seismic data. The channel complexes are oriented northeast-southwest across a gently inclined depositional slope.*

architectural elements. These interpretations were further integrated with well data to infer the distribution of depositional facies, thereby improving the understanding of reservoir connectivity. Despite these efforts, the performance of subsequently drilled infilled wells revealed notable discrepancies, underlining the challenges and limitations of inferring connectivity solely from seismic data.

Location and geology

The WDDM (West Delta Deep Marine) concession is located 50-100 km offshore in the deep water of the present-day Nile Delta, covering 6150 km^2 along the northwestern margin of the Nile cone. Most gas fields within WDDM are hosted in Pliocene turbidite slope channel systems (Figure 5a). These channel complexes are oriented northeast-southwest to northwest-southeast across a gently inclined depositional slope (Samuel et al., 2003). The trapping mechanism for the Plio-Pleistocene reservoirs is stratigraphic at the margins of the channel belts and a combination of stratigraphic and structural along the channel strike (Figure 5b). The reservoir architecture is well imaged by 3D seismic data (Figure 6). The different stages of channel development can be inferred from analyzing the seismic amplitude maps. The gas-bearing sands exhibit a class III AVO response (negative amplitude anomaly at near offset becoming more negative or increases with offset).

The channel complex comprises of Main Channel and the related Central Channel and NW Sheet as seen in Figure 6. It represents a single canyon fill system. Within the canyon the form of reservoirs typically comprises a main core belt with leveed wings. The core belt is

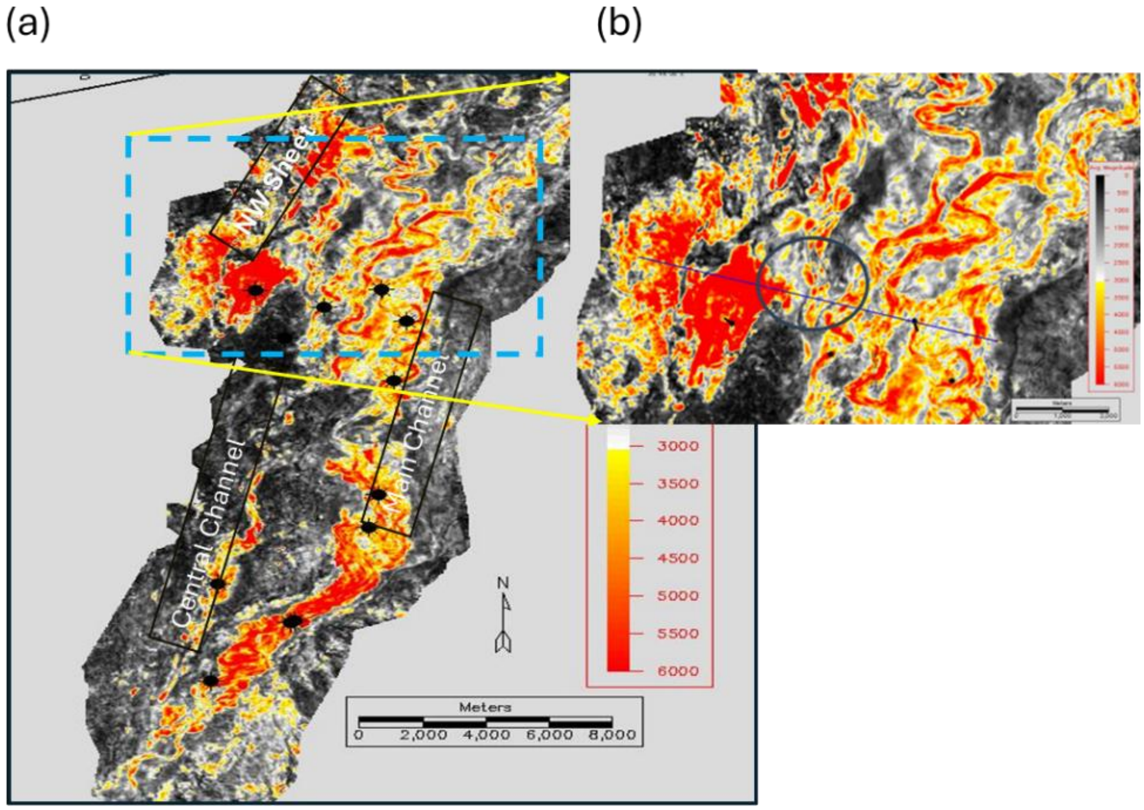


Figure 6: *Horizon slice showing a deep-water slope channel reservoir as seen on the (a) seismic amplitude, and a zoom of a small portion of the channel is shown in (b).*

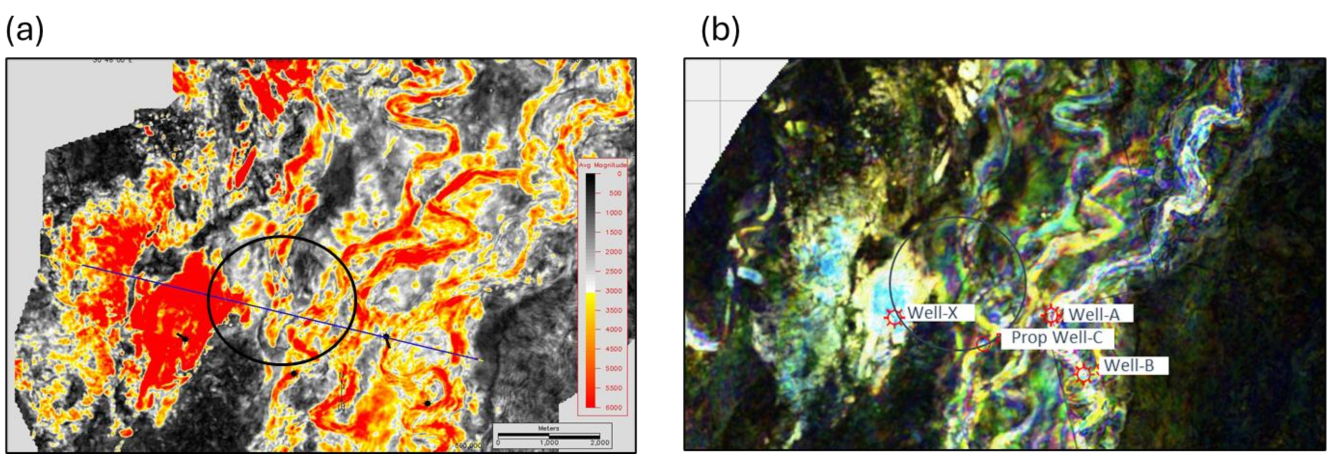


Figure 7: *Comparison of horizon slices from the (a) seismic amplitude, and (b) RGB corendered spectral magnitudes generated from the spectral decomposition of the seismic data. The channel geometry is seen defined better on the RGB corendered spectral magnitude display but there was no added value in terms of uncertainty reduction.*

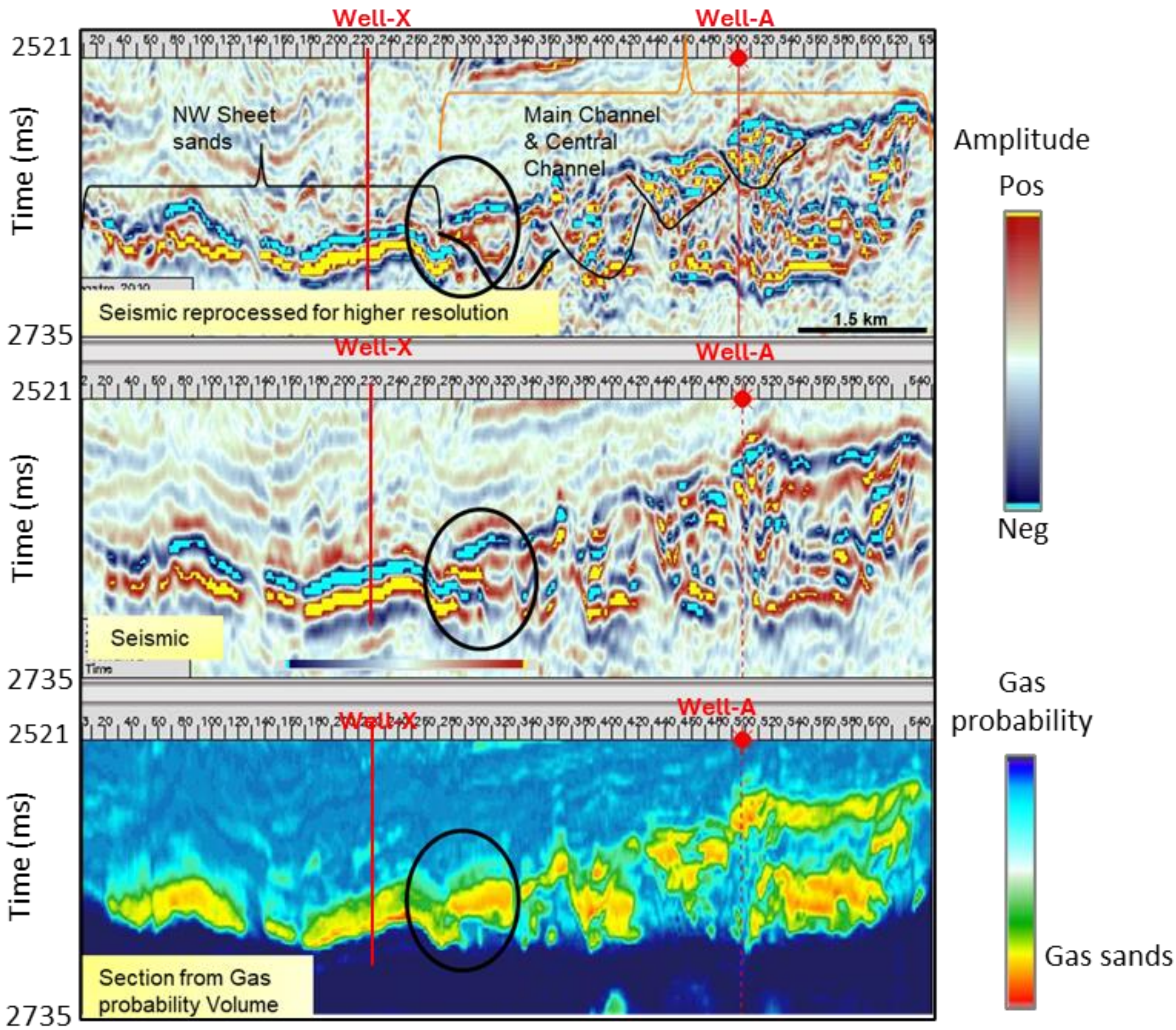


__Figure 8__: Comparison of sections passing through (reprocessed seismic data), (b) vintage seismic data, and (c) gas probability volume generated using the reprocessed seismic data. The sections pass through two wells drilled through the NW sheet (Well X), and the main channel segment(Well A). The encircled area shows a possible area of connectivity of the segments. However, infill well drilled in the NW sheet proved to be virtually isolated from the main channel.

composed of stacked channel sands, background shales and thin beds. The encircled area highlights possible areas of connectivity between different channel systems.

Based on seismic interpretation, the degree of connectivity predicted between the NW Sheet and Central and Main Channel system is assessed to be partial.

The seismic expression of the channel complex suggests likely communication between the NW Sheet and Main Channel complex in which all the producing wells are located. Spectral decomposition study was carried out to disentangle different channels and reduce uncertainty on connectivity of channels. This technique successfully enhanced the resolution of channel geometries beyond what traditional seismic amplitude maps could provide but added no significant value in reducing the uncertainty in channel connectivity (Figure 7). The seismic expression remained ambiguous in this respect (Figure 8). Due to this ambiguity, the base case reservoir model assumed a risk of partial connectivity and thus pressure depletion in the NW Sheet. However, the subsequent drilling of Well X drilled in NW sheet in 2012 after 7 years of production of wells in the main channel, encountered virgin reservoir pressure, which proved that the NW sheet is hydraulically isolated from the Main Channel complex (Figure 9).

Experiences with infill development in the WDDM have shown that it is generally very challenging to predict reservoir connectivity across faults and zones of low amplitude seismic response with great accuracy. It appears that both pressure barriers and thief zones are common at subseismic scales. Except in cases where connectivity is clearly defined, the recommended approach has evolved towards using probabilistic methods. Connectivity between reservoir segments is now typically estimated using a Monte Carlo approach, including a range of scenarios, from fully connected to fully isolated, as well as intermediate cases. As a result, connectivity becomes a key parameter during history matching, used to obtain a good match of historic pressure trends and/or water production rate. The predictions of reservoir behavior (including degree of depletion across field) and future well performance become dependent on the history matched model.

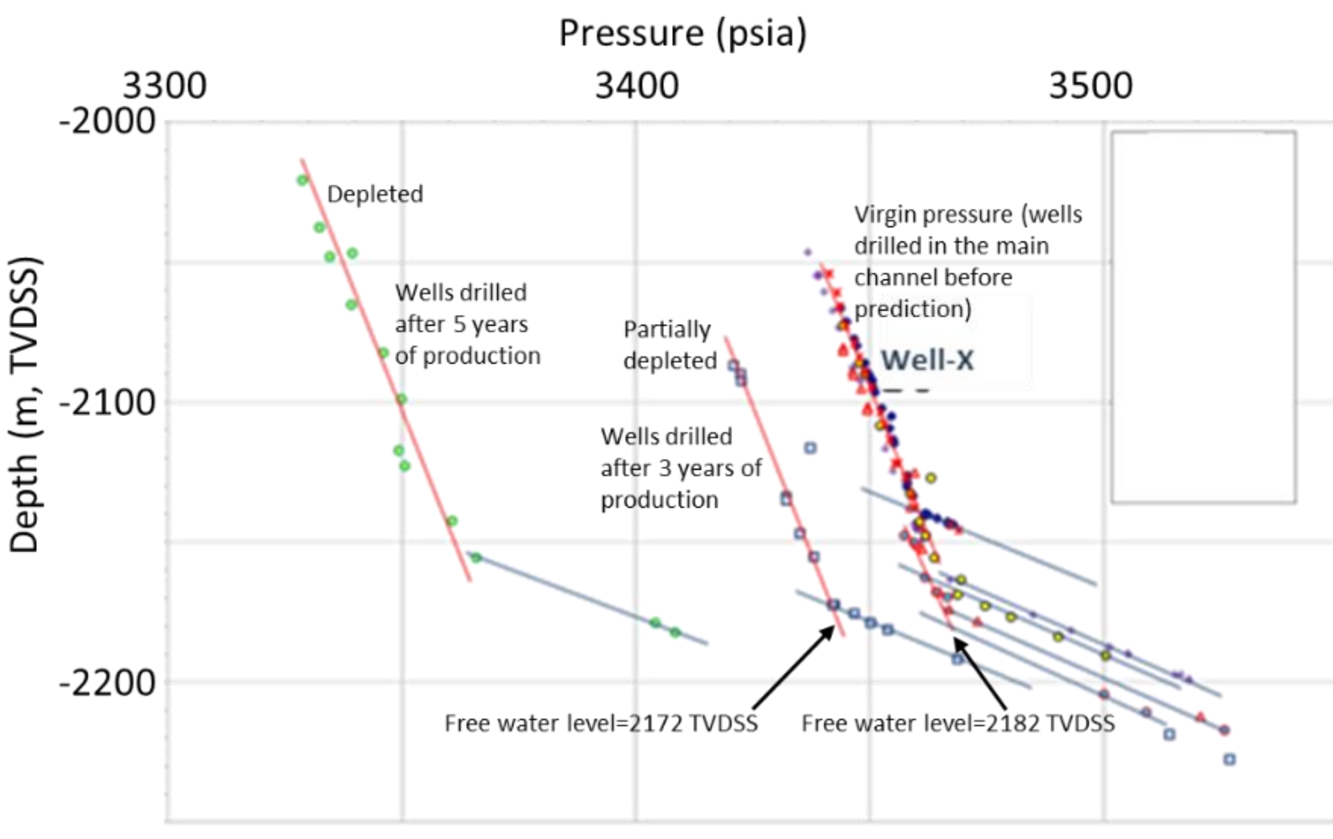


Figure 9: *Pressure plot for different wells in the area, included the data from Well X drilled in the NW sheet, which encountered virgin pressure (undepleted) and FWL (free water level) came deeper than the wells drilled in the main channel. This proved that the NW sheet to be virtually isolated from the main channel.*

SUMMARY: THE LESSONS LEARNT

The success story in 'opening new play segment' highlights the application of advanced technology in combination with a strong understanding of both regional and local geology. Compartmentalization/ uncertainty in connectivity of reservoir is a major uncertainty in the life of a field and very critical for infill development. The second case study further emphasizes the fact that considering a wide range of geological models to characterize geological possibilities and collaborating across disciplines is key in reducing the uncertainty and improving reservoir characterization.

As our industry expands into increasingly challenging areas such as deep-water settings, geologically complex basins, and areas with significant stratigraphic variations, a two-pronged approach is essential. This includes both geoscience-focused technological innovation, as well as robust interdisciplinary collaboration and communication.

REFERENCES

Aal, A., A. El Barkooky, M. Gerrits, H.-J. Meyer, M. Schwander, and H. Zaki, 2006, Tectonic evolution of the eastern Mediterranean Basin and its significance for the hydrocarbon prospectivity of the Nile Delta deep-water area, GeoArabia, 6(3), 363–384. https://doi.org/10.2113/geoarabia0603363

Annual gas market report 2024 by the Doha, Qatar based Gas Exporting Countries Forum (GECF) available at https://www.gecf.org/_resources/files/events/gecf-unveils-the-annual-gas-market-report-2024/gecf-agmr-2024.pdf and accessed in January 2025.

Dalland, A., D. Worsley, and K. Ofstad,1988, A lithostratigraphic scheme for the Mesozoic and Cenozoic succession mid – and northern Norway, Norwegian Petroleum Directorate, NPD Bulletin No 4.

Dou, L., Z. Wen, J. Wang, Z. Wang, Z. He, X. Liu, and N. Zhang, 2022, Analysis of the world oil and gas exploration situation in 2021, Petroleum Exploration and Development, **49**(5), 1033–1044. https://doi.org/10.1016/S1876-3804(22)60343-4

Notfors, C., Y. Xie, and S. Gray, 2006, Gaussian Beam migration: A viable alternative to Kirchoff, ASEG Extended Abstracts, 1-4. https://doi.org/10.1071/ASEG2006ab201

Mahajan, A., Conventional oil and gas exploration activity grows, but discovered volumes remain elusive, Rystad Energy report available at

https://www.rystadenergy.com/news/conventional-oil-and-gas-exploration-low-discovered-volumes, and accessed on October 2023.

Samuel, A., B. Kneller, S. Raslan, A. Sharp, and C. Parsons, 2023, Prolific deep marine slope channels of the Nile delta, Egypt, AAPG Bulletin, **87**(4), 541-560. https://doi.org/10.1306/1105021094

BIOGRAPHY

Subrata Banerjee has over 40 years of experience in exploration and development geophysics, having worked across a diverse range of geological settings, including clastics, carbonates, and salt environments, in countries such as India, Thailand, UK, Egypt, and Norway.

His expertise spans the full spectrum of geophysical workflows, seismic data acquisition, processing, and interpretation, with a particular strength in reservoir characterization and the integrated interpretation of geoscientific data for both exploration and development objectives.

Subrata has consistently demonstrated the ability to operate in technically challenging and culturally diverse environments. He is known for his collaborative approach, working effectively across disciplines to synthesize data and deliver optimized subsurface solutions.