Integrated prospect characterisation with a virtual asset team

M. Ledger[1], S. Hollingworth[1], K. Maynard[1], B. Leslie[1], F. Allo[1], A. Makrygiannis[2], J. Granli[2], E. Skare[2], T. Melgaard[2], D. Leslie[2]

[1] CGG; [2] OMV

Summary

This case study demonstrates the collaborative advantages when an Operator and a Geoscience Contractor work collectively as part of a tailor-made Integrated Virtual Asset team, to solve complex subsurface challenges in a restricted time frame.

The operating challenge was to de-risk a potential drilling candidate with a licence renewal decision pending. A poor seismic image of the key exploration prospect, caused by structural complexity above the reservoir interval, left significant uncertainty about the geological model and trap presence. Neither legacy nor contemporary re-processing of the seismic data had suitably resolved the target. A much-improved image and understanding of the subsurface was needed to confidently assess the quality, connectivity, and likely fluid fill of the reservoir.

A bespoke team was assembled from subject matter experts in seismic imaging, rock physics, and geological interpretation to address these uncertainties. The Integrated Virtual Asset Team undertook FWI velocity updates to form a new high-resolution reflectivity FWI Image (Zhang et al., 2020), correlated reflectivity with Pseudo-Wells simulated via rock physics modelling, and then interpreted the volume to derive the sediment provenance, depositional elements, and reservoir structure.

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A bespoke team was assembled from subject matter experts in seismic imaging, rock physics, and geological interpretation to address these uncertainties. Working with agility and in constant collaboration with the operator, the Integrated Virtual Asset Team undertook FWI velocity updates to form a new high-resolution reflectivity FWI Image (Zhang et al., 2020), correlated reflectivity with Pseudo-Wells simulated via rock physics modelling, and then interpreted the volume to derive the sediment provenance, depositional elements, and reservoir structure.

The project delivered a high-resolution subsurface image at the target level that facilitated new geological and trap models for the prospect.

By clearly framing the geological and geophysical problems and engaging a specialised team of experts, the operator was able to reduce uncertainty and make a well-informed license decision.

Background

This case study demonstrates the benefit of employing a Virtual Asset Team model to de-risk potential drilling candidates in an integrated and multidisciplinary manner.

Traditionally, Operators engage Geoscience Contractors to singularly process their seismic data, from raw shots to final stack with some attribute volumes. Often, there is no concurrent assessment of the nature of the target reservoirs or potential hydrocarbon resources contained within the imaged volume. Subsequent reservoir characterisation work is generally undertaken by the operator, a different business line within the imaging contractor, or a third-party contractor. Operators then attempt to integrate these distinct work packages to form their ultimate understanding of the asset.

The goal of the Virtual Asset Team model is to parallelise and fully integrate these distinct work packages to deliver a holistic understanding of the subsurface. The team is focused on addressing the clearly defined challenges and risks of the prospect, and generating a subsurface model that supports robust decision-making processes.

Methodology

The operator had access to a legacy reflectivity volume within the license area that had been created as a regional subsurface image and lacked a specific focus at the reservoir level. Proprietary reprocessing of the single-azimuth, towed-streamer data was undertaken to improve the resolution at target depths. Traditional signal processing with Kirchhoff pre-stack depth migration did not deliver the necessary uplift in image quality to adequately de-risk the play and allow an informed decision to be made regarding license renewal. In fact, an enhanced seismic image alone could not contain enough information and would need to be supported by a robust analysis of the physical rock properties of the reservoir target, with an accompanying prediction of potential fluid phase and a qualified assessment of the potential trap and seal integrity.

With an impending license decision, the operating challenge was then clear: could our subsurface understanding and subsequent business decisions be better supported by exploiting a more holistic approach to seismic imaging, rock physics reservoir analysis, and geological interpretation?

The key to meeting this business objective was to take a novel approach to this subsurface imaging challenge. Rather than working just on improving the image, a bespoke team would be formed from subject matter experts across the broad range of subsurface geoscience disciplines. Such a Virtual Asset Team brings together a Seismic Imaging Geophysicist, a Rock Physics Expert, and a Geological Interpreter to work across the boundaries of their disciplines with a singular objective of reducing uncertainty of the prospect. The team would integrate its processes both internally and collaboratively with the operator. Daily meetings internally and twice-weekly meetings externally would be used to monitor progress and plan work tasks necessary to meet the required objectives.

Achieving the objectives within the restricted timeline necessitated an agile working methodology. Discussions with the operator at project inception designed a flexible workflow to assess the ‘Critical Risk Elements’. The work plan included Full Waveform Inversion (FWI) velocity model update and FWI Imaging (Zhang et al., 2020); Rock Physics Modelling via the creation of Pseudo-Wells tied to the extant reflectivity data to evaluate rock properties and likely pore fluids; and Geological Interpretation to define the origin of the reservoir sediments, their depositional environments, and the contemporary reservoir structure including an evaluation of closures and seal integrity.

The culmination of the Virtual Asset Team’s work would be an overall assessment of the reservoir to define Trap Presence, Reservoir Presence, and Quality and Containment sufficient to support the operator’s decision to renew or relinquish the exploration licence.

Results

Seismic imaging work focused on improving the image definition and resolution with the use of Time-Lag FWI (Zhang et al., 2018) to produce a high-resolution velocity model and FWI Image. Imaging work began with the legacy velocity model from 2018 (suitably smoothed to remove extant high-resolution features) and raw shot data (with a mild de-noise) as inputs to the full wavefield modelling and velocity inversion. The imaging process was informed by input from the Geological Interpreter, who, at each stage, provided assessment and guidance (including depth ties at significant surfaces) as the imaging progressed towards a more coherent, well-resolved image of the subsurface.

The FWI velocity update produced a velocity model with significantly improved detail and resolution compared to the legacy versions. Using the FWI Image of this velocity model, the increased detail was transferred from velocity to reflectivity. The uplift in quality of the reflectivity volume was expressed by reduced rugosity / crenelation at regional events below the target, positively indicating that the FWI model had converged towards accurately matching the observed velocities through the shallow mass transport complex (MTC). The new image updated the structure throughout the MTCs and down through the target sediments, with the spatial extent of various units and their connectivity/fault boundaries becoming more discernible [Figure 1]. The FWI results provided improvements in the velocity model and the reflectivity image, which were then integrated with the Rock Physics and Geological Interpretation of the prospect.

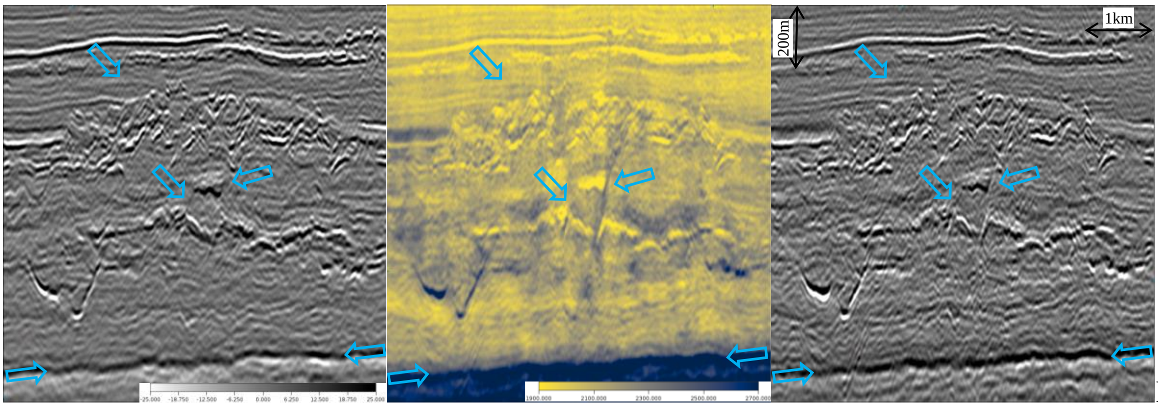

Figure 1. *Legacy Kirchhoff Stack (left), FWI Velocity (centre), FWI Image (right) showing improved imaging of onlaps onto the MTC, clearer faults and compartmentalisation at target with improved surface topography at base of key unit.*

A workflow based on statistical rock physics modelling (Allo et al., 2021) was used to build pseudo-wells at three target locations, each with distinct seismic responses compared to the surrounding area. These pseudo-wells were updated to honour the new FWI reflectivity image and velocity model to predict the most likely reservoir properties and fluid phase scenarios for the prospect. Simulated rock properties (porosity and mineral volumes) were constrained by four analogue wells located within 10 to 100km of the prospect area and translated into elastic attributes (density, P-wave, and S-wave velocities) using a series of calibrated rock physics models (Allo, 2019). Fluid substitution modelling highlighted the impact of the presence and phase of potential hydrocarbons in the prospect on both elastic attributes and seismic response. Finally, AVO analysis (Li et al., 2003) and acoustic inversion [Figure 2] of legacy seismic data were performed to identify likely hydrocarbon-charged sandstones.

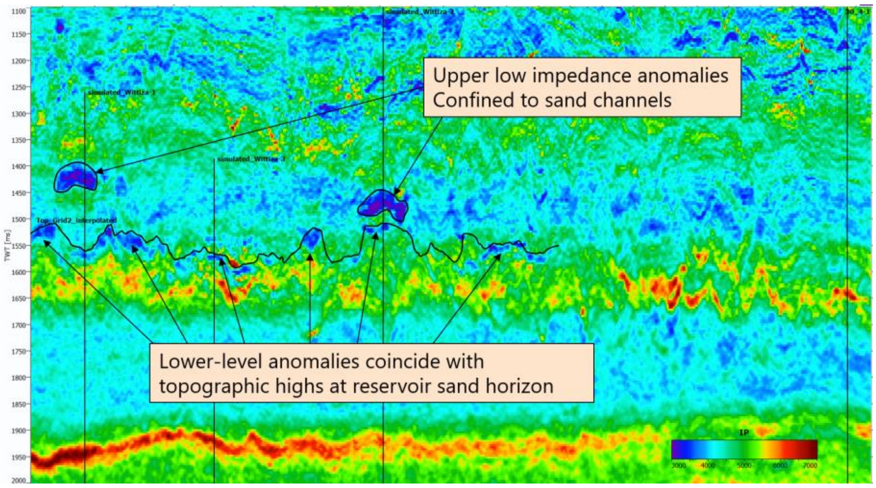

Figure 2. *Acoustic inversion of legacy seismic data*

The geological interpretation integrated the results of the seismic imaging and rock physics modelling with stratigraphic and automated fault interpretation. The assimilation of all these facets delivered a robust prospect with an improved understanding of the depositional model and trap configuration. An improved image of trap complexity and integrity helped to identify potential for vertical and lateral compartmentalization within the prospect. Seismic attribute analysis and stratal slicing were performed to assess sediment distribution and provenance, interpret depositional facies of the reservoir, and better define the extent of the prospect [Figure 3]. Automatic detection of injectites via a deep learning U-Net trained on representative North Sea analogues (Sancheti and Hou, 2023) helped assess the prospect's depositional and deformation history. This work was integrated with previous sedimentological and stratigraphic studies to refine the most likely geological model and correlate the local geological model into the regional setting.

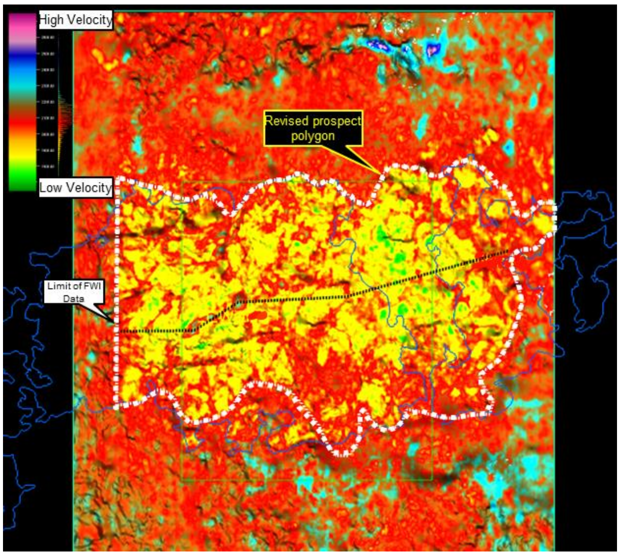

Figure 3. *Map of Minimum Interval Velocity within the target interval defines prospect extent.*

Conclusions

The Virtual Asset Team model, designed as a collaborative vehicle between operator and geoscience contractor, was able to deliver all project objectives within a particularly challenging time frame. The new FWI seismic data provided an enhanced image of the trap and reservoir discontinuities, plus an increased resolution of the reservoir depositional elements within the prospect. The integration of rock physics models and the geological interpretation reduced the uncertainty of the reservoir provenance and depositional processes. A revised prospect polygon defining the depositional model and trapping configurations was produced, with rock physics models indicating the most likely fluid fill of the prospect. As a direct result of two months' work, the operator was confidently able to make a well-informed decision with regards to the exploration license renewal.

The success of this limited study was sufficient proof-of-concept to support further integrated virtual asset teamwork, expanding the volume of study from 25km^2 to 600km^{2}to incorporate additional prospects in new lithological units.

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