INTRODUCTION

The Laverda Canyon development wells are part of the Greater Enfield Project (GEP), developing the Laverda Canyon, Norton over Laverda (WA-59-L) and Cimatti (WA-28-L) oil accumulations (Figure 1). These reserves will be produced via a 31 km subsea tie-back to the Ngujima-Yin Floating Production, Storage and Offloading facility (FPSO), located over the Vincent Field. Production from the Vincent Field, 50 km offshore Exmouth, Western Australia, began in 2008.

The project, with Joint Venture participants Woodside Energy Ltd and Mitsui E&P Australia, consists of twelve long step-out, horizontal development wells targeting multiple fault blocks with thin reservoir targets. These development wells are designed to maximise completion length in the target reservoir to optimise well productivity and sweep efficiency, and to minimise compartmentalisation risk.

Subsurface uncertainties include seismic depth uncertainty and sub-seismic features (faults, late stage channel fills). Such uncertainty can erode project value due to missed reservoir sections (late entry and/or reservoir exits), and the associated cost of corrective actions (e.g. sidetracks or infill wells).

Managing seismic depth uncertainty through seismic re-processing and a real-time update process was key to the successful placement of the Laverda Canyon development wells in 2018.

SUMMARY

Managing seismic depth uncertainty is a key consideration in placing horizontal development wells into thin reservoir targets. Seismic depth uncertainty has the potential to erode project value through missed reservoir (late landing or reservoir exits) and/or the cost of corrective actions (e.g. sidetracks). The placement of Laverda Canyon development wells in 2018 utilised a 30 Hz full waveform inversion velocity model and deep directional resistivity data in combination with a near real-time depth update process to optimise well placement.

Utilising these methods resulted in a significant reduction in seismic depth uncertainty which culminated in the final Laverda Canyon development well (LAV04WI) being successfully geosteered for ~2,200 m within a 10-15 m thick reservoir with only one reservoir exit.

Key words: Geosteering; Seismic; Uncertainty; Oil Development.

PRE-DRILL UNCERTAINTY PREDICTION

A pre-drill seismic depth uncertainty of +/- 15 m at top reservoir level away from well control was used. This seismic depth uncertainty is consistent with historical predicted versus actual from offset exploration, appraisal and development wells in adjacent fields.

Figure 1: Location of the Greater Enfield Project, offshore Australia

SEISMIC RE-PROCESSING

Seismic depth uncertainty was identified pre-drill as a key subsurface risk to well placement. Re-processing of the Laverda 3D seismic survey was undertaken in 2018 to mitigate seismic depth uncertainty risk thereby ensuring well placement was assisted by the latest technology available. Re-processing included advanced source and receiver de-ghosting, and a full 30Hz full waveform inversion (FWI) and tomographic velocity model. A similar re-processing workflow applied to another North West Shelf field is described in more detail by Dickinson et al. (2017). The re-processed data were delivered during the drilling of the first development well. Re-processing resulted in reduced seismic depth uncertainty, significant improvement in imaging at top reservoir level and a high-resolution velocity model that more clearly delineates overburden features (Figure 2). Additionally, the re-processed data enabled a more accurate delineation of high reservoir quality targets within the gross reservoir package.

ULTRA-DEEP DIRECTIONAL RESISTIVITY DATA

Top target reservoir map was constantly updated during drilling of the Laverda Canyon development wells using logging while drilling (LWD) ultra-deep directional resistivity (UDR) data to
image the boundary between the resistive, oil-filled reservoir and overlying conductive shale (Figure 3). The top of the target reservoir could be inferred throughout most of the Laverda Canyon campaign using UDR data. UDR data enabled predicted versus actual top reservoir to be calculated along the entire length of the 8-1/2” production sections by calculating the difference between the pre-drill velocity model depth and depth determined from UDR data. UDR data therefore enables the accuracy of seismic depth models to be evaluated along 2D lines, a step change in comparison to 1D data generated by well intersections which the industry has relied upon until now.

**WELL CONSTRAINED TOMOGRAPHY**

Key reservoir surfaces and seismic volumes were depth-converted in near-real time prior to drilling each section. The velocity model update was undertaken using well constrained tomography (WCT). WCT is based on tomographic principles in which depth errors are converted to errors along zero-offset rays to calculate the error in the velocity model. WCT is a global inversion process to solve a tomography matrix, with different geological constraints applied independently to each layer. This technique is fast to run as it requires only vertical ray tracing to minimise the mis-ties observed between wells and seismic. WCT consists of five key steps (Mancini, 2013; Agarwal et al., 2016).

1. Depth convert seismically-interpreted surfaces from time-migrated domain
2. Calculate depth mis-ties for each surface
3. Grid the mis-ties into maps
4. Perform 3D grid tomography to minimise depth mismatch at all surfaces
5. Depth-convert target horizons with new velocity model and calculate new depth mis-ties.

Calculating depth mis-ties for each surface (step 2) is an important step because it controls the final velocity model. Well tops are required to calculate depth mis-ties at the well locations. Well tops for this project were driven from both well intersections and interpreted UDR datasets spanning the long offset trajectories. Careful quality control of the UDR data is required to ensure the depth of the geophysical top is close to the true depth of the surface.

The mis-tie gridding process (step 3) controls how the velocity model is updated away from the wells. Different gridding methods can result in vastly different mis-tie maps. Gridded surfaces were reviewed to select the best gridding method, ensure geological plausibility and minimise gridding artefacts.

3D grid tomography (step 4) transforms depth errors into time errors. Then, the error in the velocity model is calculated by projecting the time errors along zero offset rays and minimising the vertical difference between the observed and modelled travel times. Figure 3 shows the mis-ties at top reservoir, a clear trend could be identified, pre-WCT, while a similar map post-WCT demonstrates the better convergence of residuals.

WCT limited changes in each layer to preserve the original character of the FWI 30Hz velocity model while still matching the offset well depths to an accuracy of less than 2.5 m (Figure 4). This approach for time to depth conversions combines numerical optimization and mathematical iterations to produce a velocity model which better matches the geology than traditional depth conversion methods.

WCT updates were performed before drilling the 12-1/4” and 8-1/2” sections of the five Laverda Canyon development wells as new data became available. Turnaround times were accelerated to support trajectory optimization between hole sections, and to guide decision making during geosteering of each hole section.

The real-time update process proved a valuable well placement tool culminating in the successful drilling of the final Laverda Canyon development well (LAV04W1). A significant reduction in seismic depth uncertainty was achieved by the start of the LAV04W1 8-1/2” section when compared to the pre-drill uncertainty. LAV04W1 was successfully geosteered for ~2,200 m within a 10-15 m thick reservoir with only one reservoir exit (Figure 3). This exit is interpreted as due to a steep-sided erosional feature. This feature was only partially resolved pre-drill (Figure 3). UDR interpretation of such small-scale depositional features demonstrates that they contribute to an irreducible seismic depth uncertainty of at least +/-5 m.

**CONCLUSIONS**

The successful placement of the Laverda Canyon development wells supports a flexible approach to project execution with seismic re-processing, continual re-defining the reservoir target and associated trajectory updates.

Significant reduction in seismic depth uncertainty was achieved through seismic re-processing and a near real-time depth conversion update using well constrained tomography. These processes ensured that the placement of Laverda Canyon development wells was aided by the latest technology, and the latest offset well data. This lead to increase project value by maximising the length of the wells within the reservoir, being able to target the highest quality reservoir and decreasing the risk of corrective actions (i.e. sidetracks).

**ACKNOWLEDGEMENTS**

The authors would like to thank the GEP joint venture partners Woodside Energy Ltd and Mitsui E&P Pty Ltd for permission to publish the work. This work is being published on behalf of the integrated GEP subsurface team. The authors also wish to thank CGG for their assistance with seismic re-processing, and Schlumberger for assistance with UDR acquisition and interpretation.

**REFERENCES**


Figure 2: Comparison of the 2011 Legacy velocity model (top) and the 2018 FWI velocity model (bottom). 3D images in the depth domain.
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van Ruth, Agarwal and Gagen

AEGC 2019: From Data to Discovery – Perth, Australia

Figure 3: LAV04WI development well resistivity canvas (purple well trace showing GR log). Top and base reservoir interpretations are shown as stippled white lines. Significant improvement in depth prediction observed between the 2011 (green) top reservoir surface, and the 2018 (black) top reservoir surface tied after the 12-1/4” landing.

Figure 4: Histogram of mis-ties (including exploration wells) before well constrained tomography and after the development drilling campaign.