High resolution velocity estimation using refraction and reflection FWI: the Fortuna region, offshore Equatorial Guinea.

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Summary

The primary objective of this project was to improve the understanding of the internal structure of the Viscata and Fortuna reservoirs, and this objective was met via clearer internal imaging of these reservoir intervals and the overlying gas-charged sediments.

The underlying geophysical challenge was the presence of extensive, but small-scale low-velocity gas pockets, which gave rise to significant and cumulative image distortion at target level. This distortion had not been resolved in a vintage 2013 broadband preSDM project, as the velocity model was not sufficiently well resolved. But in the initial commercial phase of this project, high-resolution non-parametric tomography using improved broadband deghosted data enabled us to achieve the stated objectives.

The follow-on work, considered here, deals with the use of full waveform inversion, to see if we could further delineate small-scale velocity anomalies, associated with the highly compartmentalized reservoir units.

Introduction

In a recent 2016 depth imaging project, the primary objective was to improve the depth structure and to obtain a clearer understanding of the internal structure of the Fortuna and Viscata reservoirs. The shallower Fortuna reservoir is gas charged and low velocity, which distorts the time structure of the underlying Viscata reservoir. The reservoirs are located in water depths of 1750 m. The Fortuna reservoir is at about 2550 m sub-sea and seen at 3250 ms TWT. The Viscata reservoir is at about 2850 m sub-sea and seen at 3500 ms TWT.

The data had been previously processed in 2013 through a broadband preSDM sequence including SRME. But it was thought that improved broadband processing together with high resolution non-parametric tomographic velocity model building and preSDM would help to enhance seismic data for reservoir delineation. The underlying geophysical challenge was the presence of extensive, but small-scale low-velocity gas pockets, giving rise to significant and cumulative image distortion at target level. The extensive nature of these low-velocity anomalies makes it impractical to pick them manually, so a robust automated technique was required. This distortion had not been resolved in the vintage processing, as the preSDM velocity model was not sufficiently well resolved. In the 2016 processing, these objectives were met.

The additional work presented here, concerns the estimation of high resolution velocity fields, as interpretation guides, using both conventional full waveform inversion FWI (primarily exploiting refraction energy), as well as reflection and reconstructed-wavefield FWI.

Multi-azimuth TTI tomographic velocity model-building for the initial model

This FWI study followed-on from a previous commercial project (Fruehn et al. 2017) wherein six MAZ tomographic model building updates using Kirchhoff and beam TTI migration were employed (Jones 2010, 2015). This included using wavelet tracking non-parametric (generalised move-out) picking of offset or angle gathers (Fruehn et al., 2014, Luo et al., 2014) to update velocity and epsilon. Figure 1 shows an inline from the final 3D TTI preSDM image with velocity overlay.

Input data preparation for FWI

A minimal pre-processing route was adopted for preparing the data for waveform inversion. Swell noise attenuation and de-bubble only were applied. Bandpass filtering was also applied but this varied depending on which iteration was being undertaken. Overall, three pass-bands were used during the many iterations; namely 1-3-5-9Hz, 1-3-10-12Hz, and 1-3-16-20Hz.

In addition, the offset range was restricted to only the far offsets during the early iterations which were relying primarily on refracted arrivals. Later iterations, when reflections were being used, did not restrict the near offset trace. In all cases, the direct wave was muted on input to the inversion, but was used as an initial QC of the forward modelling.

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Figure 1: preSDM image with velocity overlay, from the final 2016 processing.

Waveform inversion

Starting from the structurally constrained TTI tomographic velocity mode (Figure 2) after some mild smoothing, several iterations of refraction FWI were performed, focusing on the far-offsets (Figure 3). This resulted in a significant uplift in the fine-scale structure of the very shallow gas anomaly events near the seabed, but was limited in its vertical reach to around 3km depth (near the upper reservoir unit).

Subsequent iterations using RFWI, after opening the offset range so as to encompass the full reflection section, resulted in the velocity model shown in Figure 4.

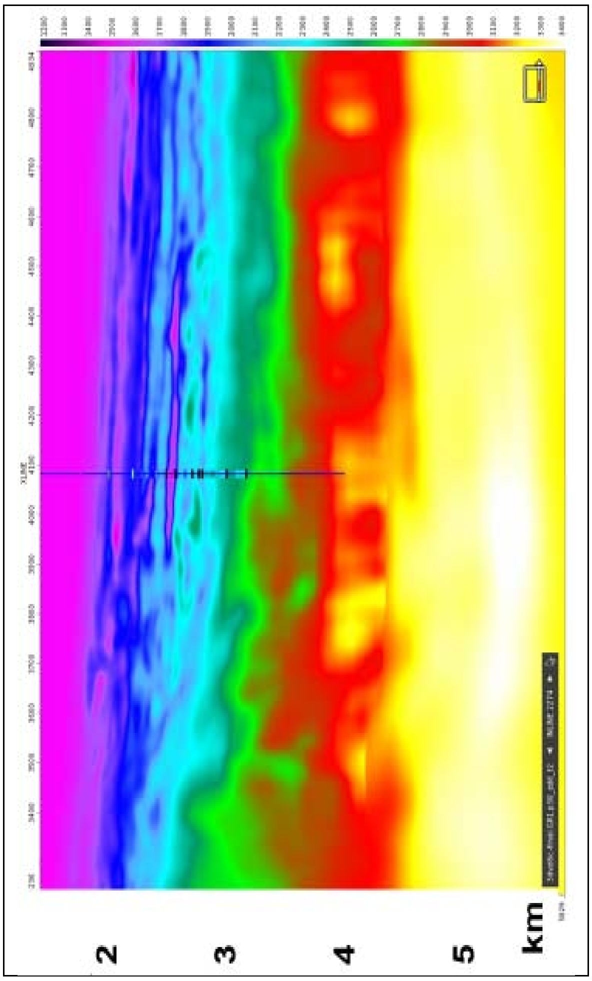

Figure 2. Velocity model derived using several iterations of structurally constrained TTI tomographic inversion: this parameter field was well-suited to imaging the complex structure of the reservoir units

The anisotropy parameters were also updated, but only after rounds of several iterations of waveform update of the velocity. Having exploited the reflection, the reach of the update now extends well below 4km, giving some new insight into the structure of the deeper reservoir unit. The depth slices in Figure 5 compare the tomographic and 20Hz RFWI results, clearly indicating the higher resolution of the velocity field, as expected from a waveform based approach.

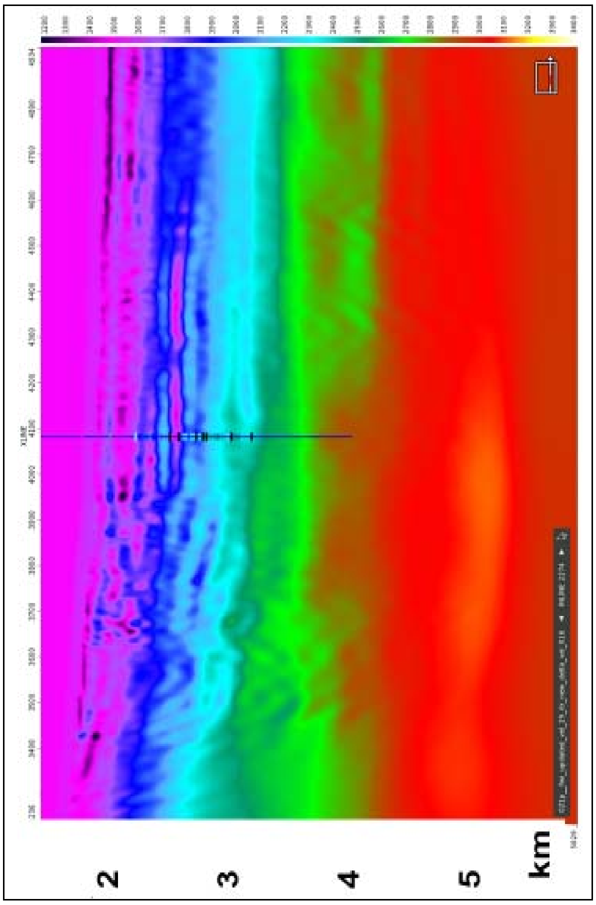

Figure 3. Conventional FWI using the transmitted (refraction) wavefield, within the bandwidth 1-3-5-9Hz, delineating subtle near surface velocity variation, and yielding better lateral resolution than ray tomography.

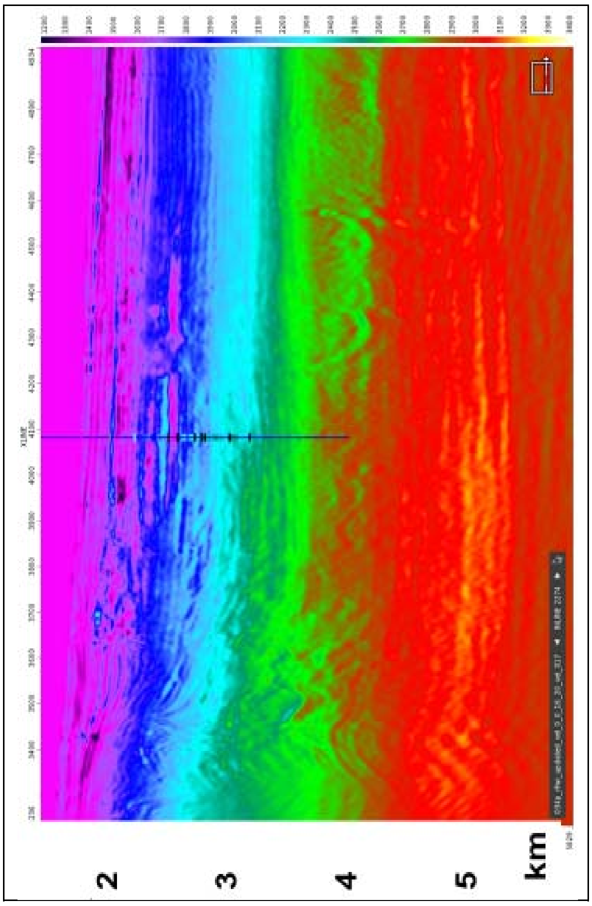

Figure 4. RFWI using both the transmitted (refraction) and reflection wavefields, within the bandwidth 1-3-16-20Hz. The deeper reservoir units at ~2650m are now well resolved

Conclusions

Detailed imaging of the internal reservoir structure of the Viscata and Fortuna fields, has been achieved, using a velocity model derived from several iterations of ray-based tomographic inversion, using structural constraints and non-parametric moveout picking. In addition, a velocity model obtained using 20Hz RFWI was derived to serve as an interpretational guide. This model delivered slight improvements to the image and gathers, but its main interest is in serving to complement the elastic impedance inversion result derived from the conventional tomographic preSDM workflow.

Acknowledgements

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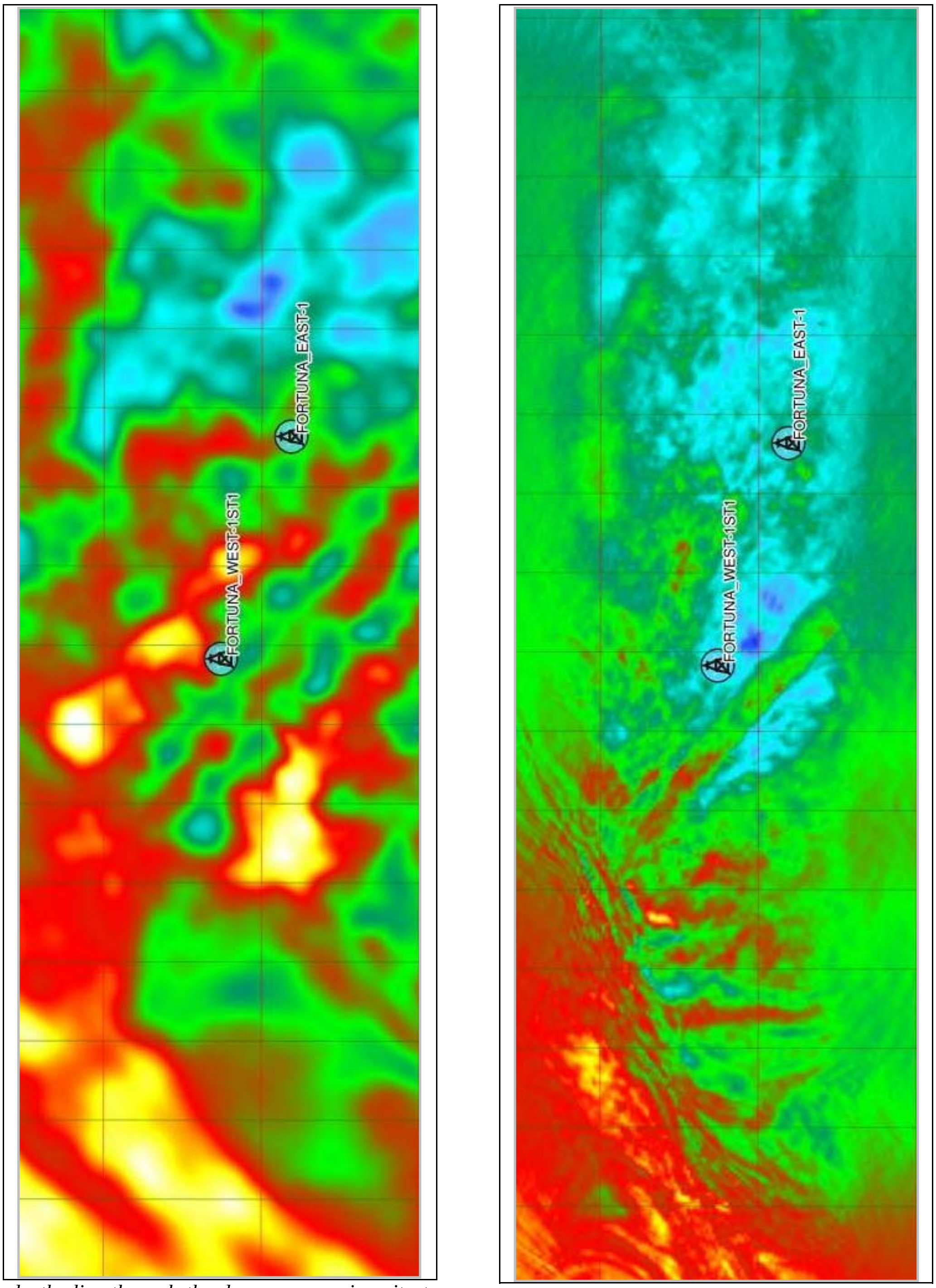

Figure 5. depth slice through the deeper reservoir unit at 2650m for the tomographic result (left) and the 20Hz RFWI result (right).