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Integrating FWI Models and Broadband Data for Elastic Property Generation, What is Appropriate?

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Summary

Full waveform inversion (FWI) produces high-resolution earth models, the use of which can improve seismic imaging. FWI can also help create absolute inversion products, by filling the low frequency spectral gap in the integration with amplitude seismic data. However, what frequency should be used for FWI to cost-effectively estimate absolute elastic properties remains an open question. We present analysis from a case study in the Norwegian Sea. Initially we demonstrate how imaging challenges have been overcome by the use of FWI and high-end imaging. Following this, we reveal there is a cost-benefit sweet-spot for the low frequency models from FWI and broadband seismic amplitude data in the generation of absolute seismic inversion products.

Introduction

Reservoir geoscientists gain a better understanding of the subsurface by integrating seismic and well measurements. Seismic data that is band-limited in frequency creates a distorted view of the subsurface. Quantitative interpretation integrates geology, pre-stack seismic analysis and well information, and has become more accurate since the advent of broadband seismic data (Reiser et al., 2012). Integrating amplitude and attributes can describe the internal structure of the reservoir; characterizing key elastic properties such as acoustic-shear impedance and Vp/Vs ratio. These increase the probability of separating lithology-fluid facies and enable more reliable predictions of lithology and fluid properties by elastic property estimation from seismic data.

To derive absolute elastic attributes for lithology and fluid prediction, a low frequency model (LFM) is needed to fill the gap between zero and the lowest useable broadband seismic frequency (Figure 1). This LFM is achieved by collocated co-kriging of seismic velocity and well information. Broadband seismic requires a low frequency model to fill the 0 to 3-4 Hz range, reducing the importance of the well information. The results of broadband prestack seismic inversion are primarily seismic data driven with the wells used only for the amplitude/wavelet calibration.

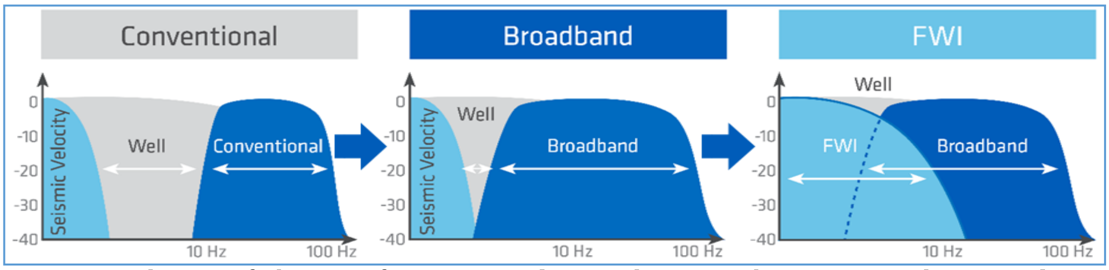

Figure 1 *Evolution of the gap frequency reduction between the seismic velocity and amplitude seismic data – more data driven than model driven solution.*

Full Waveform Inversion (FWI) creates higher-resolution velocity models than traditional reflection tomography. Both high-resolution FWI models and broadband seismic data can provide the LFM for elastic property generation, enabling well information to be a control point. Reservoir geoscientists can then confidentially derive reliable elastic attributes such as acoustic impedance and Vp/Vs ratios away from the well locations (Feuilleaubois et al., 2017).

Methodology

Velocity models have not been used as a proxy for an image as the high frequency approximations and sampling considerations used in conventional ray-based velocity model building methods prohibited this. FWI creates high-resolution models, closing the gap between imaging reflectivity and traditional model-driven trends. Until recently, FWI created high-resolution models for shallow data by using transmission waves only, limiting updates to the deepest turning point for the maximum acquisition offset. Ramos-Martinez et al. (2016) introduced a full wavefield FWI where both transmitted and reflected data are combined without user intervention. The approach eliminates the migration isochrones that dominate the gradient in heterogeneous media, enabling deeper updates for the same offset. The recent trend in the industry is to increase the seismic frequencies used for FWI, but what is appropriate for both seismic imaging and integration for elastic properties estimation?

Example

The 3D data presented here is from an HD3D broadband survey acquired by PGS, covering an area of 5,500 km^2 in the Outer Vøring area of the Norwegian Sea (Naumann et al., 2018), where several gas discoveries have been made. Full wavefield FWI was required as no transmission was recorded for an offset of less than 7 km. Small-scale velocity variations and sharp velocity contrasts between the ooze bodies and surrounding lithology were captured with high geological fidelity using a multi-scale FWI approach using seismic data up to 27 Hz. In this study area, we present absolute elastic property attributes generated using two FWI velocity models (12 and 27 Hz); broadband seismic data and a very simple rock physics model.

The two wells in the area were used only as validation points. FWI velocities were converted to impedance through a relationship derived from the regional rock physics study. The FWI LFM was merged at various frequencies with the estimated scaled relative acoustic impedance derived from the amplitude data, which has frequencies from 4 to 60 Hz (Figure 2).

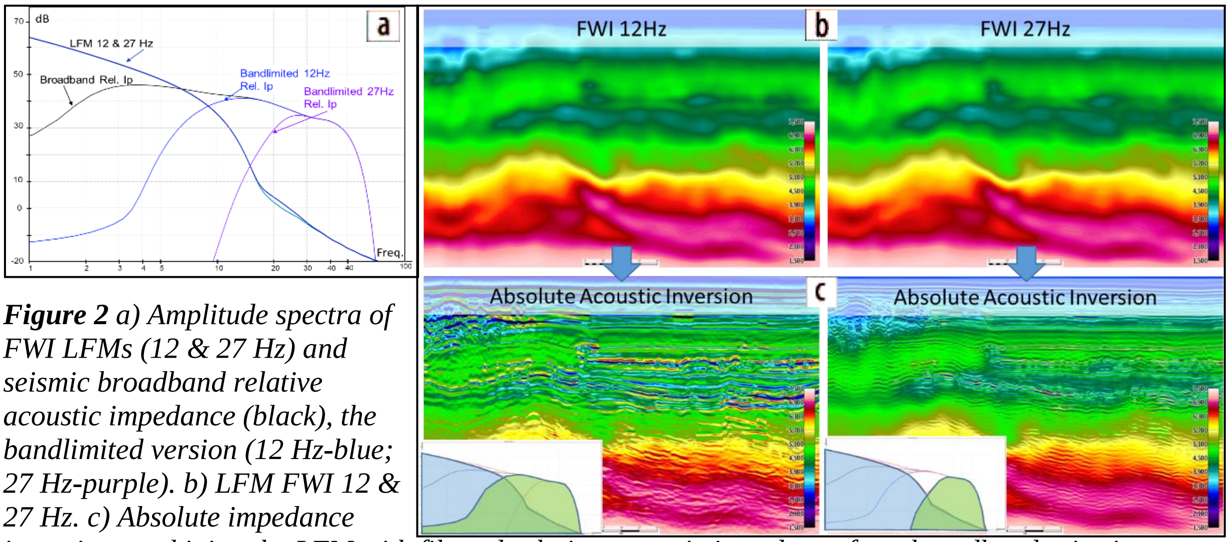

Figure 2 *a) Amplitude spectra of FWI LFMs (12 & 27 Hz) and seismic broadband relative acoustic impedance (black), the bandlimited version (12 Hz-blue; 27 Hz-purple). b) LFM FWI 12 & 27 Hz. c) Absolute impedance inversion combining the LFM with filtered relative acoustic impedance from broadband seismic.*

Figure 2 illustrates the results of increasing the contribution from the LFM and reducing the component from the seismic amplitude inversion. Removing seismic amplitude frequencies to accommodate the higher octave contribution from the 27 Hz FWI LFM degrades the absolute inversion. Using the higher frequency FWI model does not add any information for the absolute inversion results compared to an appropriate model filling the gap to the lowest useable amplitude frequency for this broadband seismic data. Validation at the well has also been performed. FWI from lower frequencies accurately ties the well, increasing the influence of the LFM from FWI in the absolute inversion process decreases the overall match to the well acoustic impedance.

Conclusions

FWI models were used to test the LFM for elastic property generation. Whilst integration of an FWI model and broadband data enables the exploitation of both for elastic property generation, broadband amplitude data dominates for the seismic inversion, whereas high-resolution FWI models solve isolated imaging issues in complex geological settings such as those found in the Outer Vøring Basin**.**

Acknowledgements

The authors would like to thank PGS MultiClient for permission to publish this work and the PGS Imaging Oslo team for the processing and imaging of this dataset.

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