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# Reservoir focused imaging with simultaneous inversion of velocity and angle-dependent reflectivity.

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## Summary

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## Introduction

The evolution of seismic imaging technologies is continuing to improve our understanding of the subsurface with more detailed and reliable information. Central to the improvements in subsurface imaging is the use of Full Waveform Inversion (FWI). In this paper, we describe and illustrate how a continuous development and consolidation of the FWI and reverse-time migration (RTM) algorithms has led to a novel inversion scheme that performs velocity estimations and least-squares migration (LSM) simultaneously. The key elements in this new approach are the modeling engine, that models the full acoustic wavefield, and the way the background (velocity) can be decoupled from reflectivity (LSM) model. Since both velocity and reflectivity are estimated independent from each other they can be used to derive other rock property attributes, like relative impedance and density, accurately. Furthermore, we describe how the inversion can be extended to the prestack domain, providing angular reflectivity, and how additional elastic earth properties can be revealed. We demonstrate this novel approach on various field data examples with different types of geology.

## Methodology

It has been well established that FWI and RTM are closely related. By exploiting the connection between FWI and RTM new flavors of FWI have been developed with the aim to combine velocity model building and imaging. Our solution to this ambition can be broken down into two key elements: the modeling engine and the imaging condition.

Firstly, if the aim is to invert for the full wavefield, then the modeling engine must have the capability to generate the entire wavefield during forward modeling, beyond the Born approximations. In our approach, the acoustic wave-equation is parametrized in terms of velocity and vector reflectivity instead of velocity and density. Whitmore et. al. 2020, showed how this formulation produces equivalent results to the conventional velocity-density formulation, without the requirement for building a detailed density model upfront. In our modeling engine, the migrated image is an estimation of the reflectivity, which acts as a proxy for the density model. With the adjoint-state method, the data-residuals will iteratively update the reflectivity model and consequently perform a data-domain LSM which will correct for false amplitude variations related to propagation effects.

Secondly, the inversion scheme must have a strategy of how the data-residuals related to kinematic and dynamic effects are addressed. Correct structural imaging requires an accurate low-frequency (background) model. Our solution to this is an imaging condition based on the inverse scattering theory (Whitmore and Crawley 2012; Ramos-Martinez et al., 2016), where the tomography and the impedance kernels are separated in FWI. With this approach, we can iteratively invert for two earth properties independently with minimum leakage, namely the velocity and the reflectivity model (Yang et. al. 2021).

The method has recently been extended to the prestack domain (Chemingui et. al 2023) by adding an additional dimension to the reflectivity model, the subsurface angle. Angle mapping and angular inversion is performed by computing the opening angle between the forward propagating wavefield (Poynting vector) and the subsurface reflectivity (or the structural dip of the reflectivity).

## Data example

A data example is shown from the Norwegian Sea, over a fault shadow zone in the Vøring basin. The underlying RTM from a recent re-processing project showed clear amplitude dimming up dip towards the large regional fault in figure 1a (annotated with an orange box). The obvious question was if these amplitude variations was related to rock property effects or caused by suboptimal focusing and illumination effects

Figure 1b and c show the LSM and the corresponding background velocity perturbation from the simultaneous inversion process. The fault shadow zone seems to be healed in the result using the simultaneous inversion, providing better consistency in amplitudes towards the regional fault and improved resolution, benefiting from the LSM 3D deblurring effects. Furthermore, the background velocity updates helped to simplify the structure and to improve the focusing. From the two inverted and decoupled parameters we can directly derive relative impedance and density, knowing that reflectivity is expressed as the directional change in impedance in our implementation. Figure 2 shows the inverted and measured relative density response and how the simultaneous inversion has correctly estimated two low relative density layers at the reservoir level, annotated with the white arrows in the zoomed display, figure 2b.

**Conclusions**

The inversion scheme described in this paper enables us to perform least-squares imaging and velocity estimations simultaneously. From the two decoupled acoustic parameters, rock property attributes like relative density and impedance can be derived, aiding the understanding of the subsurface hydrocarbon potential. With the extension to the prestack domain, additional information about elastic effects can be revealed.

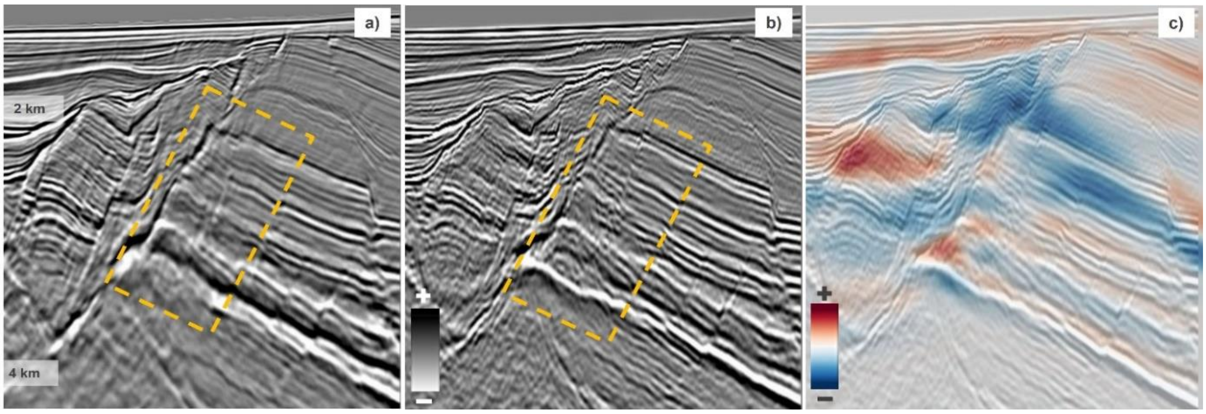


Figure 1: Comparison of RTM (a) versus the simultaneous inversion results: LSM (b) and background velocity update (c). The fault shadow zone is healed in the LSM (orange box).

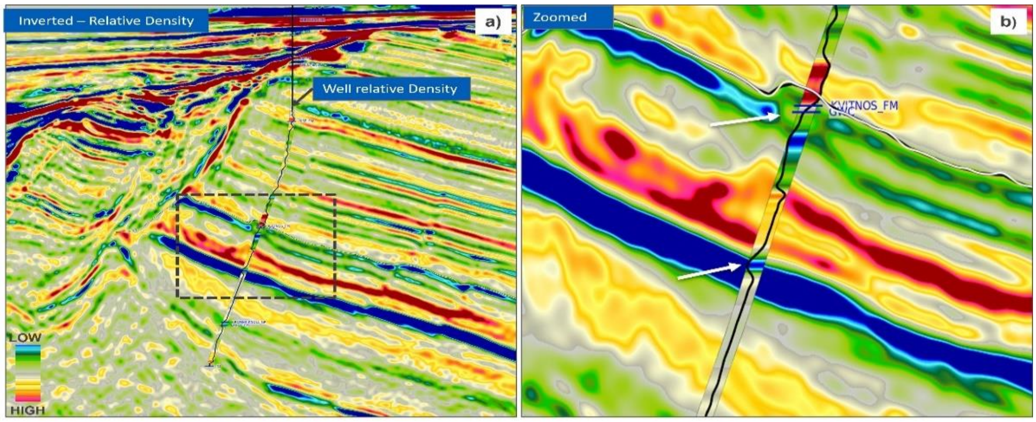


Figure 2: Relative density from simultaneous inversion compared to well density log (a). zoomed display at the target interval (b). The two low relative density layers detected by the inversion correlates well to the measured response at the well (white arrows).

**References**

Chemingui, N., Yang, Y., Ramos-Martinez, J., Huang, G., Whitmore, D., Crawley, S., Klochikhina, E. and Arasanipalai, S. [2023] Simultaneous inversion of velocity and angle-dependent reflectivity. IMAGE23, Expanded Abstracts.

Ramos-Martinez, J., Crawley, S., Zou, Z., Valenciano, A.A., Qui, L. and Chemingui, N. [2016] A Robust Gradient for Long Wavelength FWI Updates. 78th EAGE Conference and Exhibition.

Whitmore, N., Ramos-Martinez, J., Yang, Y. and Valenciano, A.A. [2020] Seismic modeling with vector reflectivity. 81st Annual International Meeting, SEG, Expanded Abstracts.

Whitmore, N. D. and S. Crawley [2012] Application of RTM inverse scattering imaging conditions. 82nd Annual International Meeting, SEG, Expanded Abstracts.

Yang, Y., Ramos-Martinez, J., Huang, G., Whitmore, D. and Chemingui, N. [2021] Simultaneous velocity and reflectivity inversion: FWI + LSRTM. 82nd EAGE Conference & Exhibition, Extended Abstracts.