**Application of elastic FWI in shallow complex geology – rejuvenation of short offset streamer data from Southern North Sea, UKCS**

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## Introduction

In recent years, elastic Full Waveform Inversion (FWI) has become standard on most seismic imaging projects. This method is considered favorable due to the ability to utilize the full recorded wavefield to resolve the pressure velocity model (Vp-model) that can reconstruct the sub-surface image correctly. Despite the early conceptional deployment of FWI (Tarantola, A., 1986), significant research continues within this field, resulting in a fast-moving technology. The research has primary focused on; improving physics in modeling (Liu *et al*., 2024), improving robustness through advanced objective-functions (Mao *et al*., 2020), parameter-decoupling, alternative imaging conditions (Ramos-Martinez *et al*., 2016) and multi-parameter inversion algorithms (Yang *et al*. 2021). All of this has contributed significantly to large evolutionary steps for the FWI results. Regardless of this, far more important is the quality of the seismic data used by the algorithm; where long offsets, low frequencies and azimuthal rich data enable full illumination of the subsurface and reduce the risk of ending in a local minima.

In this case study we make use of elastic FWI on vintage narrow azimuth (NAZ) short offset streamer datasets, with max offset of 2500 meters, in 20 meters water depth combined with large lateral geological complexity, involving chalk out-crops and salt structures. The methodology is based on elastic modeling, dynamic matching (DM) objective-function and inverse scattering imaging condition (ISIC). Despite the non-favorable input to the inversion, we demonstrate how modern elastic FWI can resolve valuable velocity estimations that improve the structural imaging. Furthermore, we discuss the limitations and alternative approaches required due to the limited available offset within the data.

## Study area

This study was conducted over the Selena license in the Southern North Sea on the UK Continental Shelf. The primary objective was to reduce structural depth uncertainty through the application of elastic full-waveform inversion (FWI), aiming to improve the resolution of pronounced near-surface velocity heterogeneities associated with chalk and salt outcrops at shallow depths beneath the seabed. The available datasets consist of two narrow-azimuth (NAZ) streamer acquisitions from 1992 and 1999, with maximum offsets of 2200 m and 2500 m, respectively.

## Methodology

To facilitate a stable FWI inversion, the modelling engine had to capture the wave-mode behavior present in ultra-shallow water, as well as the strong velocity contrasts associated with chalk and salt structures. An elastic modelling engine was therefore used, combined with careful tuning of the Vs model based on available well logs and comparisons between observed and synthetic data. The significant near-surface velocity variations place strong requirements on the conditioning of the initial model to avoid cycle skipping and convergence to local minima.

Our elastic FWI workflow utilized a dynamic matching (DM) objective function that maximizes the local windowed correlation between observed and modelled data. This leads to a phase-driven inversion that effectively reduces cycle skipping and decreases sensitivity to non-coherent noise. In addition, an inverse scattering imaging condition (ISIC) was applied to emphasize the long-wavelength diving-wave energy in the data. This prevents reflectivity

leakage during the early stages of velocity model building (VMB), when constructing the background velocity model.

During the VMB process, we analyzed the kinematic sensitivity of deeper reflections in the data domain using FWI, as well as residual moveout in the image domain. This provided insight into how the limited acquisition impacts the stability of both FWI and tomography. Based on this analysis, we realized that well-constrained interpretations, geological information and scenario-testing would be required to build the background velocity model in the deeper section.

**Results**

The initial Vp model for FWI was constructed using a combination of reflection tomography, geological interpretation, and well-based structural kriging. Due to the complex shallow geology, including chalk and salt structures, it was important to capture these heterogeneities before applying appropriate smoothing and conditioning prior to the initial low-frequency FWI stage. Available shear-wave logs were analyzed to derive Vp/Vs regression relationships for each geological layer, which were subsequently updated throughout the elastic FWI process in response to changes in the Vp model. The shallowest seismic recordings indicated a pressure-dominated wavefield, suggesting a relatively slow near-surface Vs model. This observation was used to complement the shear information from the wells.

Elastic DM-FWI was performed in frequency stages between 4 and 12 Hz, primarily using ISIC to emphasize kinematic effects relevant to structural updates. Imaging QC and FWI gradients indicated stable velocity updates down to approximately 1200 m depth (about half the cable length), resolving most of the lateral velocity variations associated with shallow rotated fault blocks and chalk pinch-outs, and resulting in improved focusing of the deeper target section. Imaging QC also showed that the gathers exhibited limited moveout sensitivity to deeper velocity variations, as well as a lack of pre-critical recorded energy in the shallowest section. Based on this, the seismic stack response was used as the primary measure to evaluate the impact of the FWI model at depth.

A similar sensitivity analysis was carried out for the deeper reflections using FWI, confirming that kinematic moveout sensitivity is limited with short-offset data. Horizon-guided scenario testing and well-constrained model adjustments were therefore performed and evaluated against the stack response to finalize the velocity model.

**Conclusions**

In this case study, we have challenged FWI using non-favorable short-offset NAZ acquisitions in a complex geological setting with significant near-surface velocity heterogeneities. We applied an elastic modelling engine combined with a dynamic matching objective function and an inverse scattering imaging condition to resolve much of the near-surface complexity, while observing how the short-offset data limits moveout sensitivity in both the data and image domain. Despite the use of advanced inversion algorithms, the input data remains the most critical factor for FWI performance. We demonstrate that geological understanding and interpretation-driven scenario testing remain essential when FWI is constrained by the acquisition design.

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