High-resolution imaging of seismic properties in the Porcupine Basin by full waveform inversion of long-streamer data

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Summary

The Porcupine Basin is a failed rift located in the North Atlantic margin offshore southwestern Ireland. This hyper-extended basin was formed after several rifting and subsidence phases during Late Palaeozoic and Cenozoic, with the most pronounced rift phase occurring in Late Jurassic-Early Cretaceous times. From the perspective of hydrocarbon exploration, the Porcupine Basin is one of the most attractive areas in the Irish Atlantic domain with potential hydrocarbon systems within the post-rift stratigraphic sequence (i.e. Cretaceous and Tertiary sediments). Yet, this area is not properly explored and little is known regarding the properties of the rocks, such as porosity and fluid content, both critical for reservoir characterisation. In this work, we seek to characterise the Porcupine Basin by building high-resolution, quantitative models of seismic properties along 2D sections of the basin by full waveform inversion (FWI) of long-streamer data. FWI is a state-of-the-art imaging technique able to retrieve sub-wavelength images of multiple parameters such as seismic velocities, density or anisotropy that can be linked to rock porosity and fluid content through empirical relationships. Here we present the first step of a hierarchical approach, focusing on low-frequency, long-offset refracted signals. We start from a previous model obtained by first arrival traveltime tomography (FATT), which ensures kinematic accuracy for the considered long-offset refractions and mitigates the usual cycle-skipping issue. The resulting FWI velocity model brings more details on the western margin of the basin, where FATT already identified a low-velocity anomaly in the hanging wall of the basin-bounding fault, which suggests the presence of fluids. Further steps will include the estimation of density in the fault zone and its conversion into porosity, and the consideration of higher frequencies for more detailed images. On the long term, we expect these images to provide new insights into the properties of the Porcupine Basin, the presence of fluids and their potential linkage with the growth of post-rift normal faulting, and therefore to contribute to the understanding of the tectonic history of the basin and to the characterisation of potential reservoirs.

Context and aim of the study

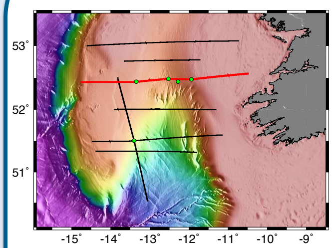


Fig. 1: Location of the selected line in the Porcupine basin (in red). Green dots indicate wells. Seismic data were provided by the Petroleum Affairs Division (PAD) of the Department of Communications, Climate Action and Environment (DCCAE) of Ireland.

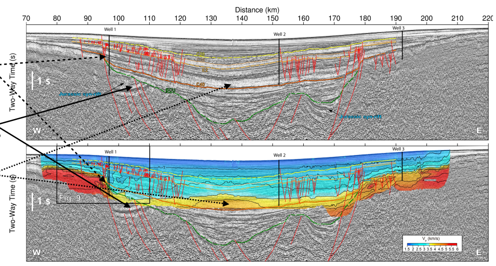
Fig. 2: Comparison of the interpreted migrated section (Saqab et al., 2017) with the starting traveltime tomography model (Prada et al., 2018).

Questions

Presence of fluids and linkage with fault reactivation?

Properties of the sedimentary packages?

Subsidence pattern?



Objectives

- **High-resolution**,
- **multiparameter** (V_P, density, V_S, Q),
- **quantitative imaging** of the shallow part of the basins (< 5-6 km).

Data and Methods

- *Data:* long-streamer (10 km) multichannel seismic data (1248 shotgathers).
- *Method:* 2D adjoint-based full waveform inversion (FWI) *seisDD* package (Yuan et al., 2015). Entire seismic wavefields are computed numerically using the spectral-element method (*Specfem2D*, Komatitsch and Villotte, 1998).
- *Starting model:* First arrival traveltime tomography (FATT, Prada et al., 2018).
- *Data processing:*
  - low bandpass filtering (5-9 Hz)
  - data mute: selection of long-offset refractions
  - 3D-to-2D conversion (Bleistein, 1986)
  - source signature estimation by linear inversion of the direct arrival propagating in deep water (Pratt, 1999).
- *Hierarchical strategy:*
  - from acoustic to elastic
  - from monoparameter (Vp) to multiparameter (density, Vs)
  - from low to high frequencies
  - from long to short offsets
  - from early to late arrivals

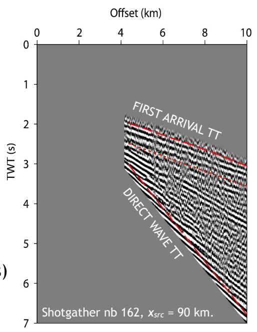


Fig. 3: Example of processed data.

Here we present the results for the very first stage of this hierarchical approach: **Vp** estimation in the **acoustic** approximation, using **low-frequency**, **long-offset** data.

Results

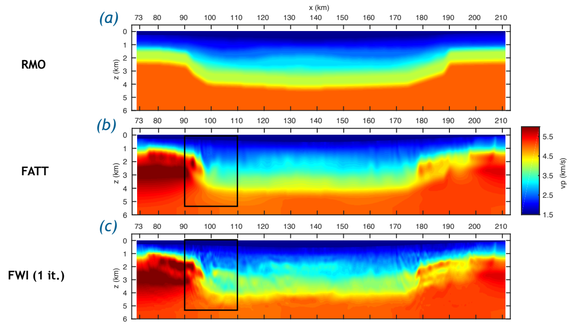


Fig. 4: (a) Interval velocity model obtained from residual move-out (RMO) analysis, used as starting model for traveltime tomography. (b) First-arrival traveltime tomography model (FATT, Prada et al., 2018), used as starting model for FWI. (c) FWI model after 1 iteration (misfit decrease 18%). The black boxes correspond to the close-up shown in Fig. 5.

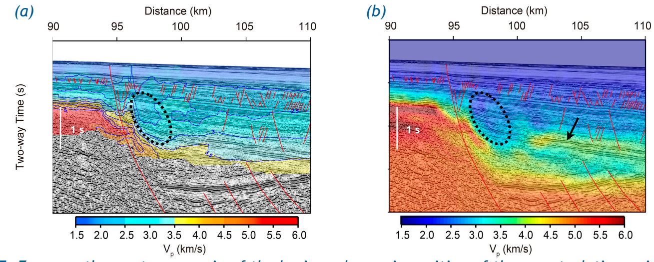


Fig. 5: Zoom on the western margin of the basin and superimposition of the pre-stack time migrated section over depth-to-time-converted models. (a) FATT model, (b) FWI model. Red lines indicate normal faults interpreted from 3D seismics (Saqab et al., 2017). Both models display a low-velocity anomaly within the post-rift strata on the hanging-wall of the basin-bounding fault (ellipse). The FWI model also highlights the chalk layer as a discontinuous, high-velocity anomaly (arrow), suggesting lateral variations in facies and/or porosity within the chalk.

Quality control: comparison of observed vs. synthetic data

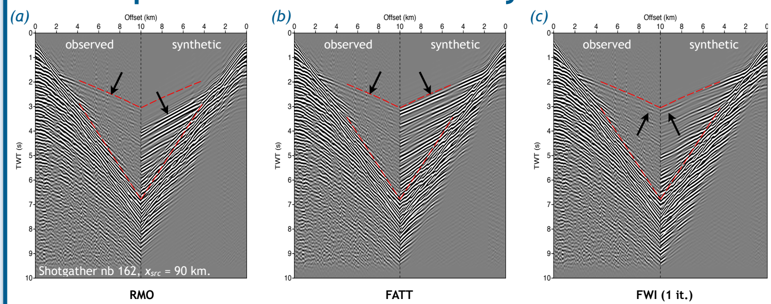


Fig. 6: Comparison of observed data vs. synthetics computed in (a) the RMO velocity model, (b) the FATT model, and (c) the FWI model after 1 iteration. The FATT model provides a much better kinematic accuracy than the RMO model, hence qualifying as a suitable starting model for FWI.

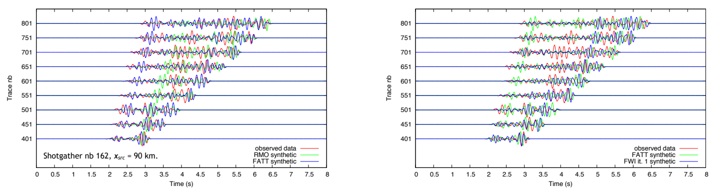


Fig. 7: Comparison of the fitted waveforms vs. synthetics computed in the RMO, the FATT, and the FWI models. (Amplitudes have been normalized and cannot be compared.)

Future work

- Consideration of higher frequencies (up to 25 Hz): more details, better resolution.
- Multiparameter acoustic FWI: joint reconstruction of Vp and density.
- Investigation of the imprint of S waves in the data, via synthetic simulations.
- Interpretation in terms of petrophysical properties (porosity, fluid content).
- Migration of the data in the new velocity models: more accurate seismic images.

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