# ESTIMATION OF AN ACOUSTIC VELOCITY MODEL FOR THE CROP M12A SEISMIC LINE USING A GRADIENT-BASED FULL WAVEFORM INVERSION

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**Introduction.** This work deals with the application of a Full Waveform Inversion (FWI) (Virieux, et. *al*. 2009) (Fichtner, 2010) procedure to increase the resolution of an acoustic velocity model related to a part of the M12A CROP marine seismic profile (Scrocca, et *al*., 2003). The CROP M12A seismic line was acquired during the Italian Deep Crust Project (CROP), aimed at investigating the structure of the deep crust in Italy. In (Tognarelli et *al*., 2010) the recorded data were re-processed to enhance the visibility and the resolution of the structures at the shallow depth up to 3-4 s two-way travel time. Nowadays, FWI represents an important tool to build a high-resolution velocity model of the subsurface from active seismic data. Such model is obtained as the global minimum of some misfit function, designed to measure the difference between the observed and the modelled data. In general, the misfit function is highly non-linear with the presence of many local minima due to the well-known cycle skipping effect (Pratt, 2008). Therefore, the optimization problem is solved by means of an iterative gradient-based method, starting from a model as close as possible to the global minimum of the objective function. Besides, the application of FWI to real data requires dedicated specific operations aimed at improving the S/N ratio and obtaining observed data that can be reliably reproduced by a modelling algorithm (Galuzzi et *al*., 2018).

In this work, we present an application of acoustic FWI on a part of CROP M12A seismic profile. Specific processing operations are applied on both predicted and observed data to increase the robustness of the inversion procedure, thus improving the reliability of the final model estimation. The predicted data are obtained by solving the 2D acoustic wave equation, whereas in the local optimization procedure the steepest descent algorithm is employed. The misfit function used is based on the $L^2$ norm difference between the predicted and observed envelopes of the seismograms (Bozdag et *al*., 2011). As the starting model, we used the model obtained by (Tognarelli et *al*., 2010) through the Migration Velocity Analysis (MVA) and used for the post-stack depth migration of the data. To validate the FWI final model, we check the improvements on the flattening of the events in the common-image-gathers (CIGs) after pre-stack depth migration.

**The seismic data.** The CROP M12A seismic dataset consists of 1500 marine seismic shots, acquired in the northern Tyrrhenian Sea, south of the Elba Island, employing an air-gun source. The direction of the acquisition is from South-West to North-East. The sources and the receivers are located at 8 m and 14 m below the sea surface, respectively. The source-receiver offset varies from 125 m to 4625 m. The receiver interval is 25 m, the time sampling is 4 ms and the record length is 17 s even if, to study the structures located at shallow depth, a two-way travel time up to 3-4 s is enough (Tognarelli et *al*., 2010). From the entire data set, we select only 100 shot gathers evenly distributed in 22 km towards the end of the line. In this part of the profile, the sea-bed is almost flat with a depth of about 90 m. Figure 1a shows the location of the M12A CROP profile. The red arrow indicates the part of the profile used for the inversion, whereas Figure 1b shows an example of a raw shot gather used in the inversion. The red polygon represents the time window used to focus the inversion on the diving waves and on the shallow reflections of the data and is defined for each seismogram.

**Modelling.** The synthetic data are obtained by means of an explicit, 2nd order in time, finite difference algorithm which is used to solve the 2D acoustic wave equation. The model dimensions are approximately 24.5 km in length and 2 km in depth. The modelling grid is made by 981x80 nodes, with a uniform grid size of dx=25m. The sea-bed is situated between the $3^{rd}$ and $4^{th}$ row of the grid. We put absorbing boundary conditions on the lateral and bottom sides

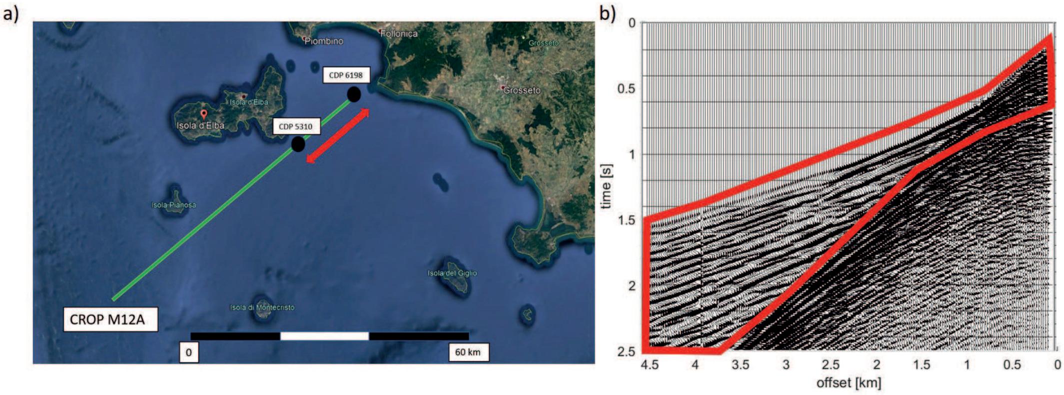


Fig. 1 - (a) Location of the M12A CROP profile. The red arrow represents the part of the profile used for the inversion. (b) An example of shot gather used in the inversion. The red polygon delimits the portion of the seismogram considered in the inversion.

of the model and reflecting boundary conditions at the top side to simulate the sea-air interface. The order of approximation of the spatial derivatives is optimized to reduce the numerical dispersion (Galuzzi et *al*., 2017). The source wavelet is estimated from the sea-bed reflection.

**Design of a robust misfit function**. Before performing the Full Waveform Inversion, dedicated processing operations are applied on both predicted and observed seismograms to reduce the cycle skipping effect and, in general, to circumvent the non-linearity of the optimization problem. As shown in previous studies (Galuzzi *et al*., 2018) (Mazzotti *et al*.,

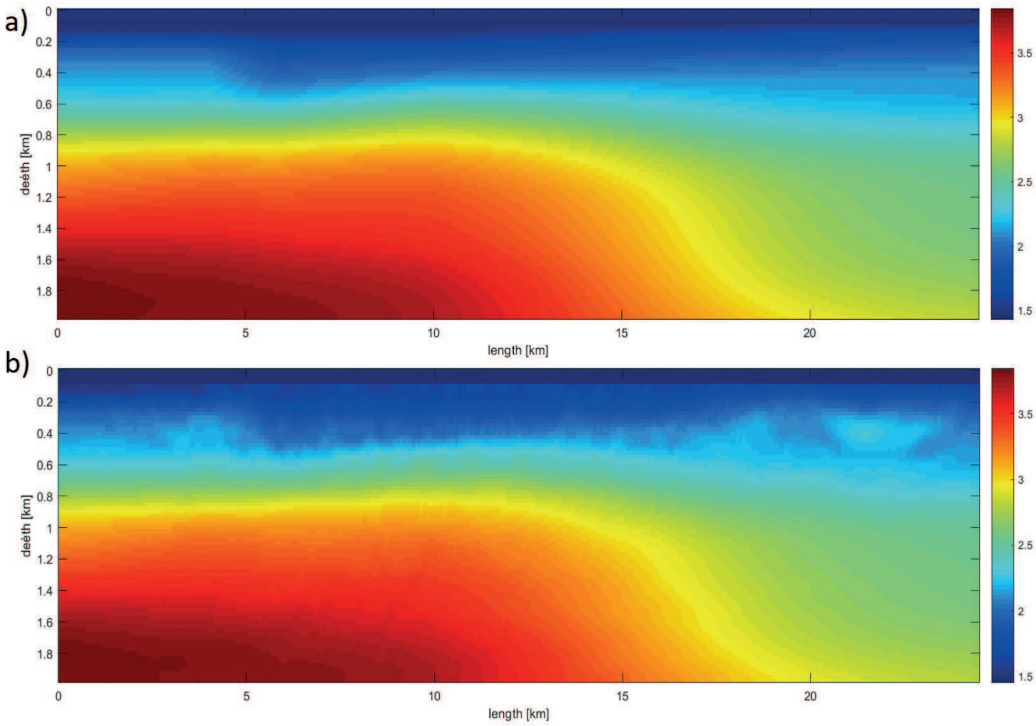


Fig. 2 - a) Velocity model obtained by the MVA. b) Velocity model obtained at the end of the FWI optimization procedure.

2017), we make use of a processing sequence that includes a band-pass filtering between 5 Hz and 15 Hz, trace-envelope computation, and trace-by-trace normalization. Finally, we choose the $L^2$ norm difference between the predicted and the observed data, as the misfit function.

**Initial model.** Due to the non-linearity of the misfit function, the starting model in the FWI procedure plays an important role. To assure the convergence of a local optimization method, the initial model must be accurate enough to give a good match between the observed and predicted data. To attain this, we make use of the velocity model obtained from MVA. More details on the estimation of the model can be found in (Tognarelli *et al*., 2010). Figure 2 shows the MVA velocity model used to pre-stack depth migrate (PSDM) the data. The migration results are illustrated in Fig. 3a where 6 GIGs evenly spaced along the profile and displayed up to 2 km of depth can be observed. The flattening of the events on the CIGs, obtained after the PSDM, constitutes a good validation test for the reliability of the MVA velocity model. However, many gathers still present a residual move-out that can be reduced using the FWI based on a gradient line-search method.

**Inversion procedure and results.** As the local optimization method, we use the steepest descent algorithm (Nocedal et *al.,* 2006), where the descend direction corresponds to the negative direction of the gradient of the misfit function, and the step length is obtained by a line search that satisfies the Wolfe conditions (Wolfe, 1969). The gradient is computed using the adjoint method (Plessix, 2006). Special attention is given to include the processing sequence in the computation of both the misfit function and its gradient. The unknowns are the velocity values on the grid nodes situated below the sea floor, for a total of 981 x 77 unknowns. The velocities range of the unknowns is between 1400m/s and 4500m/s. We perform 200 iterations for the minimization procedure. Fig. 2a and 2b show the velocity model obtained by MVA and at the end of the FWI optimization procedure, respectively. The starting model is refined mainly in the upper part just below the sea-bed.

Figure 3a and 3b show a comparison of 6 CIGs positioned along the seismic profile before and after the FWI inversion. A significant improvement of the horizontal alignment of the events at about 1 km of depth can be noted passing from Fig. 3a to Fig. 3b.

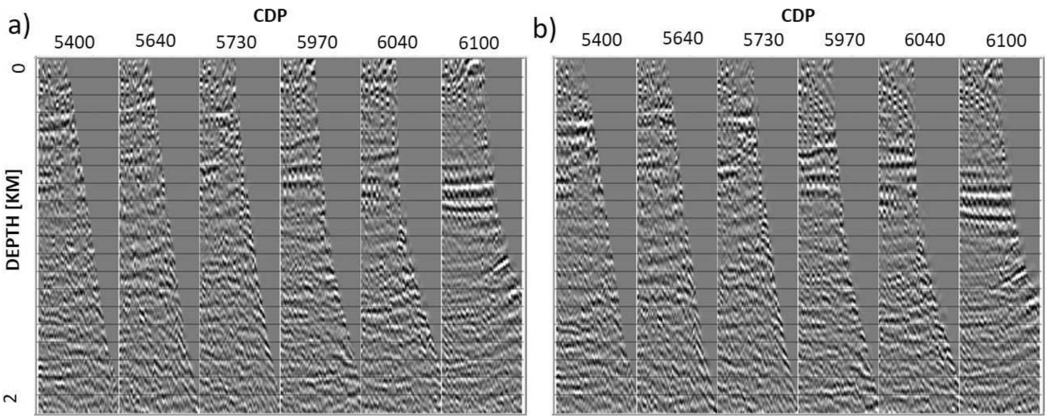


Fig. 3 - CIGs obtained by pre-stack depth migrating the data using (a) the MVA velocity model and (b) the final velocity model obtained at the end of the local optimization procedure.

Z**Conclusion.** In this work, we made an acoustic FWI experience on a portion of the CROP M12A marine seismic profile acquired in the framework of the Italian Deep Crust Project. The processing sequence applied to the data reduces the non-linearity of the misfit function and strengthens the reliability of the whole procedure against the cycle-skipping phenomenon. Starting from a velocity model obtained by the MVA, we estimated, by means of a gradient-based method, a final model whose improved quality is assessed by a better horizontal alignment of the events in the CIGs.

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## SEISMIC ATTRIBUTES IN THE INTERPRETATION OF CHANNEL GEOMETRIES: THE CASE STUDY OF THE CONGO BASIN

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**Introduction.** Seismic attributes are commonly used in the oil & gas industry to improve the interpretability of seismic data (Taner *et al.*, 1979; Chopra and Marfurt, 2008). The application of this technique to enhance the presence of geological features like channelized systems and faults may be helpful to extrapolate additional information from data, therefore improving the seismic interpretation potential. It may also help to identify and optimize study's techniques for further processes of seismic interpretation.

We applied this technique to geological features of the lower Congo Basin. The geological framework of the area is the Angolan Passive Continental Margin. In this area the channelized systems of Zaire River and the wide fan of the Congo Basin develop with a length of about 800 km westward and a width of more than 400 km from Gabon to Angolan margins. The study region is characterised by turbidite systems within the Miocene deposits of the Malembo Formation, in a framework of extensional tectonics (Sikkema *et al.*, 2000; Savoye *et al.*, 2009).

Throughout the application of attributes that enhances local signal variations, changes in amplitude, phase and frequency, it was possible to highlight acoustic impedance contrasts,