APPLICATION OF ACOUSTIC GLOBAL FWI ON A SHALLOW SEISMIC REFLECTION DATA SET ACQUIRED IN LUNI (TUSCANY)

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Introduction. The archaeological site of Luni in Tuscany (Italy) is located on an alluvial plain where geological surveys carried out in the field recognized different units such as alluvial fans of the Magra river, sedimentary swamps and sand bars (Bini *et al.*, 2006), all indicating a flat layer stratification of the shallow subsurface. The archaeological context of the site makes Luni a very interesting location for the application of various geophysical techniques, such as GPR, electrical tomography and magnetic surveys. Furthermore, the good seismic response observed in previous seismic reflection and refraction tests, makes also Luni attractive for a seismic reflection survey aimed at investigating the near-surface layers for a more detailed geological study. All these motivations lead us to the acquisition of a reflection seismic data set that can also be used for the application of different processing and inversion algorithms especially tailored to the near-surface investigations.

In this work, we describe the processing and the results of a preliminary 2D acoustic Full Waveform Inversion (FWI) of a seismic reflection data set acquired in Luni. The processing is carried out to obtain the best image in time and also to estimate a preliminary interval velocity field (by means of the Dix equation) that is later used as input to the pre-stack depth migration. Successively, a global 2D acoustic FWI is applied to produce a more accurate velocity field in depth. We make use of a parallel implementation of a genetic algorithm (GA) optimization (Sajeva *et al.*, 2016), where the data misfit is evaluated as the L2 distance between the envelope of the predicted and observed data on the first arrivals to reduce the non-linearity of the misfit function. Pre-stack depth migrated common image gathers (CIGs) computed with the obtained velocity field show a good horizontal alignment of the observed reflections.

Seismic data set. In this experience, the equipment used consists of 48 vertical component geophones with characteristic frequency of 10 Hz connected to two seismometers by a cable with 48 channels. Receivers spacing is 2 m and shot distance 1 m. The spread configuration is mainly off-end, but towards the end of the line, to spare time, the cable is held fixed and the shot position gradually enters in the spread. This acquisition configuration allows to have a maximum offset of around 100 m and a mean fold coverage of 50, even if not uniformly distributed. The choice of the source is dictated by the requirement to have a high number of shots to grant the possibility of source array forming. Therefore a 10 kg sledgehammer is used even if the depth of penetration is lower with respect to a seismic gun. With this kind of source

185 blows are recorded in just 2 days of field work resulting in a profile length of approximately 180 m. Sampling interval is 0.5 ms and record length 1 s. A more detailed description of the acquisition layout is given in (Tognarelli and Stucchi, 2016).

Processing sequence. The processing sequence applied is aimed at obtaining the best image of the shallow subsurface reflections in terms of signal-to-noise ratio (S/N) without bringing in unwanted artifacts. To this goal, we first spatially filtered the raw field data in the laboratory by Chebyshev weighted arrays to reduce the surface waves and air blast effects (Tognarelli and Stucchi, 2016). Successively, each step in the sequence is designed to increase the S/N ratio of the reflection events, carefully checking the output to ensure that no artifacts are introduced. In short, the processing procedure includes: band-pass filtering, refraction statics corrections, velocity analysis, deconvolution, residual statics computation, f-x deconvolution and stack. Fig. 1 shows the stack section obtained at the end of the described sequence.

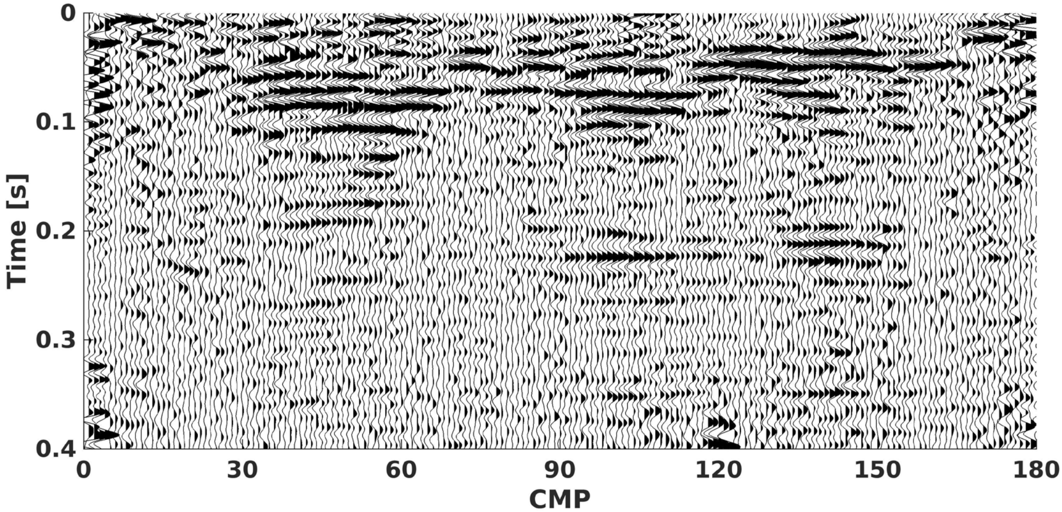

Fig. 1 - Stack section obtained at the end of the time processing sequence.

FWI inversion. Due to the oscillating nature of the seismic wave propagation, the classical L^2 distance between predicted and observed data is characterized by many local minima that hinder the convergence of the inversion towards the true model corresponding to the global minimum. One approach that can be followed to reduce the non-linearity of the FWI and that allows a more robust inversion, is the application of some processing steps to the data, such as filtering and muting, that also allow to select the phases on the seismogram to invert (Tognarelli *et al.*, 2015). This is an important issue in the near-surface exploration because the source related noise contamination (ground-roll), together with the limited recorded offset, reduce the portion of the data that can be used in an acoustic FWI.

We select 20 shot gathers along the profile, approximately one shot every 10 m, and for each record we design appropriate mute functions that include only the first arrivals. Trace envelope to recover some low frequencies, trace normalization and low-pass filtering (0-15 Hz) are then applied to the first arrivals of the observed and predicted data before computing the L^2 distance. Some attempts to infer the source wavelet from the real data are carried out. However, the use of the envelope in the inversion allows to relax the requirement of an accurate source wavelet, whose estimation is a very difficult task especially for near-surface seismic investigation. Figure 2. shows an example of a raw shot gather (Fig. 2a) and the corresponding observed (Fig. 2b) and predicted (Fig. 2c) data used to compute the misfit function.

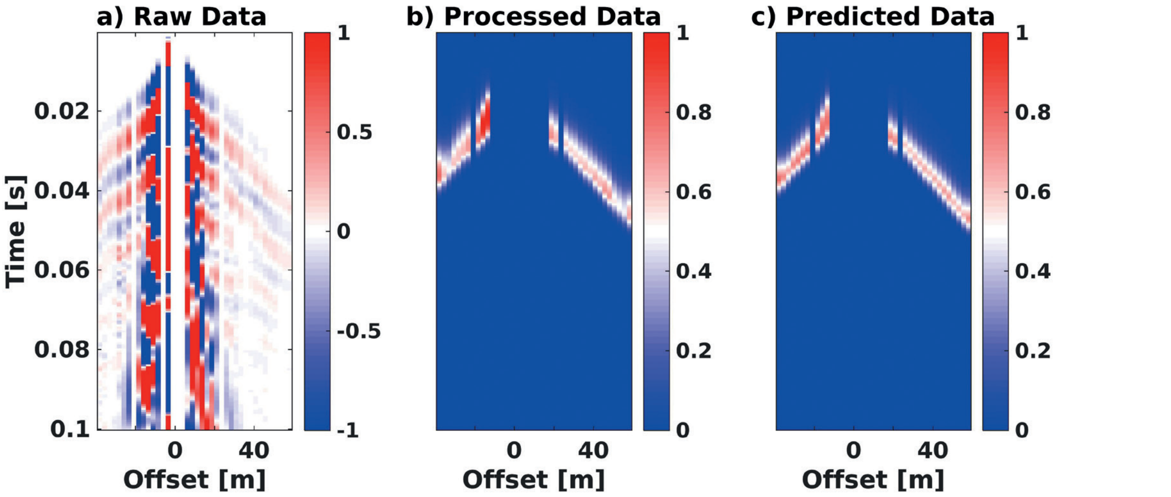

Fig. 2 - a) Raw shot gather after the array filtering; b) observed data for the shot in a); c) predicted data for the same shot.

The inversion was carried out using the genetic algorithms as the optimization method and using the two-grids strategy as described in Sajeva et al. 2016. The fine grid covers a model of 188 m in length and 260 m in depth and has a node spacing of dx=dz=2 m. The coarse grid consists of 20×3 nodes with a vertical spacing of 13 m and a horizontal spacing of 63 m, due to the limited horizontal velocity variation expected in the investigated area. The unknowns are the velocity values at the coarse grid nodes. The starting velocity model was derived from the smoothed and depth converted model (Dix equation) computed by the velocity analysis step. The parameters used for the genetic algorithms are chosen to allow a good exploration of the model space (the number of individuals in each population is 15 times the number of unknowns) and a fast rate of convergence (selection rate 80%). To reduce the possibility to be entrapped in a local minimum, 2 sub-populations are used along with 1.67% of mutation rate.

The velocity model obtained after the GA inversion is illustrated in Fig. 3a., as can be expected, it shows mainly a flat layer stratification that well corresponds to the stack image shown in Fig. 1, with some minor lateral velocity variations. No wells are drilled, so to verify

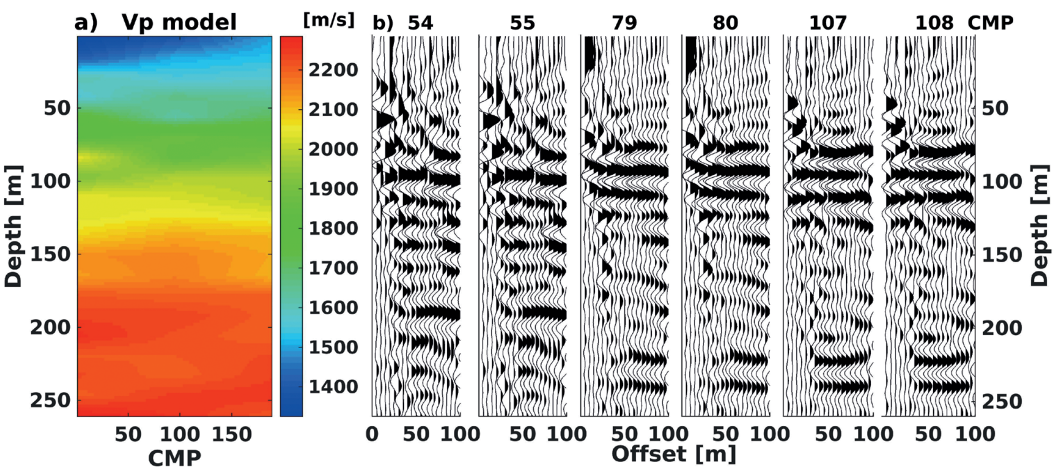

Fig. 3 - a) Velocity model estimated by the GA; b) CIGs after pre-stack depth migration.

the accuracy of the velocity model we pre-stack depth migrate the seismic data after muting the first arrivals and check the alignment of the reflections on the CIGs. As can be observed in Fig. 3b. the results are quite satisfactory.

Conclusions. We present the preliminary results of an acoustic Full Waveform Inversion applied on a seismic data set acquired for near-surface investigations. The velocity model obtained making use of only the envelope of the first arrivals allows to compute CIGs that show a fair horizontal alignment of the observed reflections. This result represents a first step towards a more complete procedure of FWI in which the full seismic wavelet and the reflections are integrated.

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