Introduction

We present a depth-domain processing flow-chart based on iterative ray+Born prestack depth migration/inversion coupled with an automatic post-processing of the quantitative migrated image. The migrated image computed by ray+Born inversion is a limited bandwidth version of the true velocity model, i.e., a model of short-scale velocity perturbations. The limited bandwidth of the migrated image, which results from the limited bandwidth of the source wavelet and from the limited aperture coverage provided by multichannel seismic reflection geometries, degrades the resolution power of both the structural and lithological interpretations of the velocity perturbations. Aim of the post-processing is to remove the limited bandwidth effects from the migrated image in order to build a structural velocity model. The post-processing consists of a Very Fast Simulated Annealing (VSFA) optimization where the input data are vertical profiles of the migrated image and the output models are the corresponding structural velocity profiles. The relation between the input and the output can be approximated by a simple time-domain convolution which makes a global exploration of the model space possible. This global exploration is required by the expected high degree of non linearity of the inverse problem (i.e., many structural velocity profiles may fit equally well the migrated profile after convolution with the source wavelet).

The overall flow chart was already presented in the frame of a real data case study whose goal was to image a décollement in a subduction zone, offshore Ecuadorian margin (Agudelo et al. (2005)). However, additional validations are required due to the absence of in situ measurements. In this paper, we assess the robustness of the flow-chart thanks to the synthetic Marmousi example. We first applied iterative single-arrival ray+Born migration/inversion (e.g., Thierry et al. (1999); Operto et al. (2000)). We show how 9 iterations of single-arrival migration have allowed us to obtain a reliable quantitative migrated image even in the areas of the model intersected by multiple arrivals. Second, the post-processing is applied to each profile of both the true Marmousi perturbation model (i.e., the true migrated image) and the computed migrated image. This comparative test allowed us to assess the sensitivity of the post-processing to small errors in the migrated image.

The depth-domain processing flow-chart

The integrated approach is subdivided into 2 main steps: (1) we first apply iterative ray+Born single-arrival migration/inversion. Only one iteration of ray+Born migration/inversion is usually applied (Thierry et al. (1999); Operto et al. (2000)). Here, we computed several iterations of ray+Born waveform modelling and inversion until the convergence was achieved in order to recover the true amplitude of the velocity perturbations as accurately as possible. In case of multiple arrivals, we noticed that several iterations of single-arrival migration/inversion allowed us to esti-
mate velocity perturbations in the areas of the model intersected by caustics as accurate as those inferred from single-iteration multiple-arrival migration (Operto et al. (2000)). (2) The limited bandwidth of the migrated images precludes a fine and quantitative interpretation of the structure, for example, in case of thin layering. We designed a post-processing whose aim is to remove the limited-bandwidth effects from the migrated image resulting from the limited bandwidth of the source and the limited source-receiver aperture coverage. The output of this post-processing is a family of structural velocity models which are consistent with the migrated image.

The post-processing is formulated as an inverse problem for which the data space is composed of several vertical logs of the migrated image (namely, the limited bandwidth velocity logs). The model space is composed of the corresponding structural velocity logs (namely, the impulse velocity logs), parameterized by a limited number of layers with random velocity and thickness. The relation between the data and the model is approximated by a simple time-domain convolution with the limited-bandwidth source wavelet. The inverse problem is solved independently for each log by a random exploration of the model space, using the VSFA algorithm (Sen and Stoffa (1995)). The uncertainty and the error analysis (central and dispersion statistical estimators) are investigated by multiple VFSA which allows to estimate the frequency of visits of each accepted specific cell of the model space discretized by layer thickness and velocity (Sen and Stoffa (1995); Jackson et al. (2004); Mosegaard and Tarantola (1995)).

**Application to the Marmousi model**

We applied the processing flow-chart to the complex Marmousi model (Fig. 1a). The macromodel for migration/inversion was built by smoothing the true velocity model with a 2D Gaussian filter of horizontal and vertical correlation lengths 76 m (Operto et al. (2000)) (Fig. 1b). We computed the true perturbation model (i.e., the true migrated image) by applying a time-domain band-pass filter to the true velocity model with a bandwidth representative of the source wavelet (5-10-35-55 Hz) (Fig. 1c). We first applied the VSFA inversion to each profile of the true perturbation model. During the search of the optimal models, VFSA samples a region of the model space, Model space is discretized by random velocity perturbations and layer thickness (by proceeding from the top to the bottom following a layer-stripping approach). To quantify the uncertainty associated with a population of fitting models, we perform multiple VFSA (Sen and Stoffa (1995); Jackson et al. (2004)). For a fixed temperature, we iterate 3 runs of VFSA and we store in a matrix the number of visits of each accepted velocity and thickness parameters according to the Metropolis criterion. For a large number of iterations, this matrix provides an estimate of the posterior probability density function (PDF) (Jackson et al. (2004)). This matrix shows that the accepted models exhibit a similar behaviour (Fig. 2a). From this matrix, we estimated the average velocity perturbations and the uncertainties (Fig. 2b). The mean velocity log converted in time domain and convolved with the source wavelet is superimposed with the migrated trace and shows a good agreement (Fig. 2c). By summing the macro-model velocity log (Fig. 2d) and the mean velocity perturbation (Fig. 2b) we obtain the structural velocity log which can be compared with true velocity log (Fig. 2e). All the output mean velocity profiles were subsequently assembled in the distance-depth domain to produce a 2D structural velocity model (Fig. 1d). Comparison between 4 velocity profiles extracted from the Marmousi velocity model and from the mean velocity model inferred from VSFA is presented in Fig. 3 (middle panels).

Second, we computed 9 iterations of ray+Born single-arrival migration/inversion. The strongest arrival was migrated. The final migrated image is shown in Fig. 1e without automatic gain control. One can note that we obtained a rather good image of the deep target. Comparison between vertical profiles extracted from the true perturbation model and the ray+Born migrated image is shown in Fig. 3 (left panels). The amplitude of the velocity perturbations are pretty well recovered even in the areas intersected by caustics. The mean 2D structural model inferred from VSFA is shown in Fig. 1f and the comparison between 4 mean velocity profiles with that of the Marmousi model is
shown in Fig. 3 (right panels). The match is slightly degraded compared to that obtained with the true perturbation model but remains enough good to consider in the future target-oriented structural interpretation of complex structures (compare middle and right panels in Fig. 3).

Figure 1: a) Marmousi velocity model. b) Macromodel for migration. c) True perturbation model which mimics a depth-migrated section. d) Structural velocity model inferred from the post-processing of the true perturbation model (c). e) Ray-Born migrated image. f) Structural velocity model inferred from the post-processing of the ray+Born migrated image (e).

Figure 2: For a profile at distance 7 km, a) Matrix of the frequency of visits of the model space (i.e. posterior probability density function). The color scale shows the frequency of visits of each specific cell of the model space. b) Mean velocity perturbation (black line) and dispersion statistical estimators (gray band) obtained from a). c) Log from the true perturbation model (black line) superimposed with the mean velocity log after convolution with the source wavelet (green line). d) Log from the smooth velocity macro-model. e) Comparison between log from Marmousi velocity model (black line) and mean structural velocity log (gray line).
Figure 3: (a-d) Left panel: comparison between vertical profiles of the true perturbation model (black) and the ray+Born migrated image (gray); Middle panel: comparison between vertical profile of the Marmousi velocity model (black) and the mean structural velocity log inferred from VSFA using the true perturbation model as input; Right panel: Same as the middle panel but the input of VSFA is the ray+Born migrated image. a) x=3 km; b) x=5 km; c) x=6.2 km; d) x=7 km

Conclusions

A quantitative integrated approach based on combined iterative ray+Born migration/inversion and global optimization (VFSA) method was validated thanks to the complex Marmousi model. This depth-domain quantitative approach could be a useful tool for target-oriented struturel and lithological interpretations in complex geological environments.

References


