Automatic robust velocity estimation by poststack Stereotomography

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Summary

Stereotomography, which is based on the concept of locally coherent events, appeared to be a fast and powerful method for velocity macro-model estimation. However, in presence of low signal-to-noise ratio and coherent noise, automatic event picking on prestack data does not guarantee reliable information and may lead to wrong velocity models. In this paper, we present a new implementation of Stereotomography where the picking is performed in poststack time domain. It allows a robust and reliable picking procedure. We show results obtained using “poststack Stereotomography” on synthetic and real examples and compare these results with the conventional “prestack Stereotomography”.

Introduction

Prestack depth imaging requires the estimation of accurate velocity-depth model. Most of the advanced velocity model estimation methods are using traveltime information for continuous reflection events and need strong human intervention/interpretation which is both subjective and time consuming. Stereotomography proposed by Billette and Lambaré (1998) opens a way for velocity model building without requiring continuous reflection events interpretation. It is based on the principle of the Controlled Directional Reception method and it uses the idea of locally coherent events. These events are described by shot – receiver positions, two-way traveltime, and slopes at the shot and the receiver. These five parameters provide all the necessary information for velocity macro-model calculation. Several slope tomography methods have been proposed last decade. A numerical implementation of the stereotomographic velocity inversion is illustrated in several practical applications. However automatic picking of locally coherent events in prestack time domain remains a critical point in the Stereotomography. Several modifications were proposed to overcome this difficulty, e.g. picking in depth migration domain (Chauris et al., 2002). But even after these improvements and modifications it is difficult to see practical use of the Stereotomography in 3D case. Here we propose to pick locally coherent events in poststack domain rather than in prestack domain and to use kinematic information regarding the picked events which is extracted from the prestack wavefield. We refer to this new implementation as poststack stereotomography. Poststack picking is a robust and reliable procedure commonly used in seismic interpretation. We use the Common Reflection Surface (CRS) method (Jäger et al, 2001) to calculate the stacked section and to extract kinematic information on the picked reflection events.

We first describe the proposed method and its implementation. Then we demonstrate on synthetic and real data that the poststack stereotomography provides results comparable to prestack stereotomography even in case of complex structural situations.

Principles of Stereotomography

Stereotomography is a slope tomography method based on the concept of locally coherent events defined in the prestack data cube. A stereotomographic dataset consists of N locally coherent events $d^r = (d_i^r)_{i=1}^N$ with $d_i^r = (s, r, p_s, p_r, t_{sr})_i$, where $s = (s_x, s_z)$ and $r = (r_x, r_z)$ are the source and receiver locations, t_{sr} is the two-way traveltime and p_s, p_r are the local slopes at source and receiver respectively. These slopes correspond to the horizontal component of the slowness vectors emerging at source and at the receiver. The model m is described as N pairs of ray segments and a smooth velocity field C , $m = \left[(X, \beta_s, \beta_r, t_s, t_r)_i\right]_{i=1}^N, \left[C_j\right]_{j=1}^M$ where each pair of ray segments is described by a reflection/diffracting point X, two emergence angles β_s, β_r towards the source and the receiver and two one-way traveltimes t_s, t_r from the point X toward the source and receiver. In this approach, the cost function is defined as a misfit for all types of input data parameters; the pairs of ray segments and the velocity model are estimated jointly by a local optimization technique based on a conjugate gradient-type algorithm. The main advantage of this approach is the fact that the picked events do not need to be interpreted in terms of reflection on any particular interface.

Poststack Stereotomography

Instead of picking events in prestack domain, we propose to pick locally coherent event in poststack time domain and to combine Stereotomography velocity inversion with the Common Reflection Surface (CRS) stack. Picking performed on a stacked section provides a reliable information on zero-offset reflection/diffraction arrival times. CRS stack is used to calculate an accurate zero-offset approximation and to extract kinematic reflection wavefront parameters from the prestack data. We use the picked zero-offset times and the corresponding kinematic parameters to calculate the prestack traveltimes and the slope information requested for Stereotomography. The CRS stacking operator can be written as:

$$t^2_{CRS}(x_0,h)=\left(t_0+2\frac{\sin\beta}{v_0}(x_{cmp}-x_0)\right)^2+2t_0\frac{\cos^2\beta}{v_0}\left(\frac{(x_{cmp}-x_0)^2}{R_N}+\frac{h^2}{R_{NIP}}\right)$$

where x_0 is the output position, x_{cmp} is the midpoint coordinate of the input trace, h is the half offset, v_0 is the near surface velocity, t_0 is the zero-offset two way traveltime. The triplet (β, R_N, R_{NIP}) defines the stacking surface associated to the zero-offset traveltime t_0 : β is the angle of emergence of the zero-offset ray, R_{NIP} is the radius of curvature of the NIP-wave and R_N is the radius of curvature of the N-wave. CRS produces an accurate zero-offset approximation (stacked section) and dense and continuous estimate for wavefront parameters β , R_{NIP} , and R_N . The poststack stereotomography procedure can be summarized as the following:

1. Calculation CRS section and wavefront parameters for each CMP position and time sample.
2. Picking locally coherent events on the CRS stacked section.
3. Prestack traveltimes and slopes calculation using the picked events and associated wavefront parameters. For each picked event at (x_{cmp}, t_0) , we compute for a given offset h:

- ➢ the source position $s = x_{cmp} - h/2$ and the receiver position $r = x_{cmp} + h/2$.
- ➢ the associated prestack traveltime $t(s,r) = t_{CRS}(x_{cmp}, h)$ using the CRS operator.
- ➢ the local slopes in the offset direction $p_h = \frac{\partial t_{CRS}}{\partial h}$ and in the CMP direction $p_m = \frac{\partial t_{CRS}}{\partial x_{cmp}}$. The local slopes at the source and receiver are given by $p_s = \frac{(p_m - p_h)}{2}$, $p_r = \frac{(p_m + p_h)}{2}$.

We then obtain a set of prestack dataset $\{s, r, p_s, p_r, t_{sr}\}$ that we use as input for stereotomography inversion.

Application on synthetic and real datasets

We first illustrate the application of the poststack Steretomography and compare results to those obtained by conventional prestack stereotomography on a synthetic dataset. Figure 1 displays a smoothed velocity model used in this example and prestack depth migration using correct velocity. The model has a complex structure and strong lateral velocity variations. Synthetic data have been computed using a Kirchhoff method, where only primary events were calculated.

For prestack Stereotomography, the automatic picking was performed on common shot/common receiver gathers. Velocity model obtained after inversion is displayed in Figure 2a. Figure 2b shows results of prestack depth migration using inverted velocity model. In this case of high signal to noise ratio and absence of regular noise, the inverted velocity and depth section perfectly resemble the correct once.

For poststack Stereotomography, we first calculate the CRS stacked section and estimate the CRS parameters. The locally coherent events were automatically picked on this section providing reliable information on zero-offset arrival times. We then used the estimated CRS parameters to calculate the prestack traveltimes and slopes requested for velocity inversion. The resulting velocity model is displayed in Figure 3a. Velocity model obtained by the poststack Stereotomography although shows some differences compared to the correct one, well recovers main features of the actual velocity model. The migrated image using this velocity model (Figure 3b) shows a good positioning of the reflectors and gives a good idea of the structure.

An application of poststack Stereotomography on a field dataset is displayed in Figures 4 and 5. The prestack depth migration shows a good positioning and focusing of the reflectors.

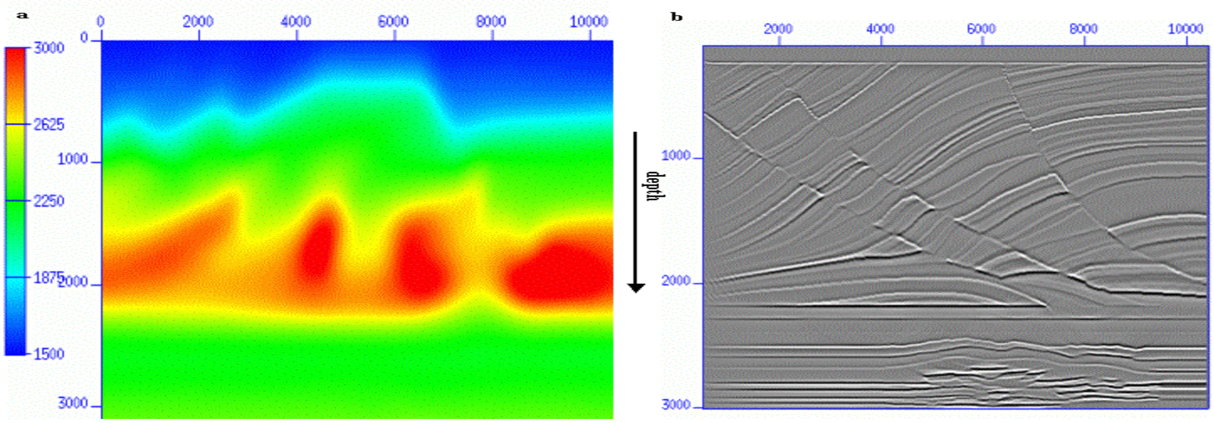

Figure 1: (a) true velocity model; (b) prestack depth migration using true velocity model

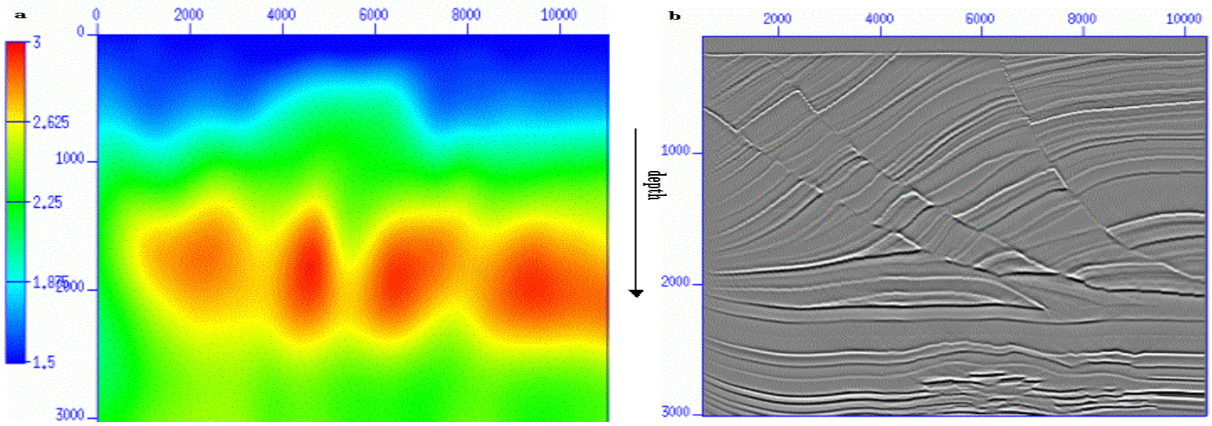

Figure 2: (a) velocity model obtained by prestack Stereotomography; (b) prestack depth migration using velocity model obtained by prestack Stereotomography

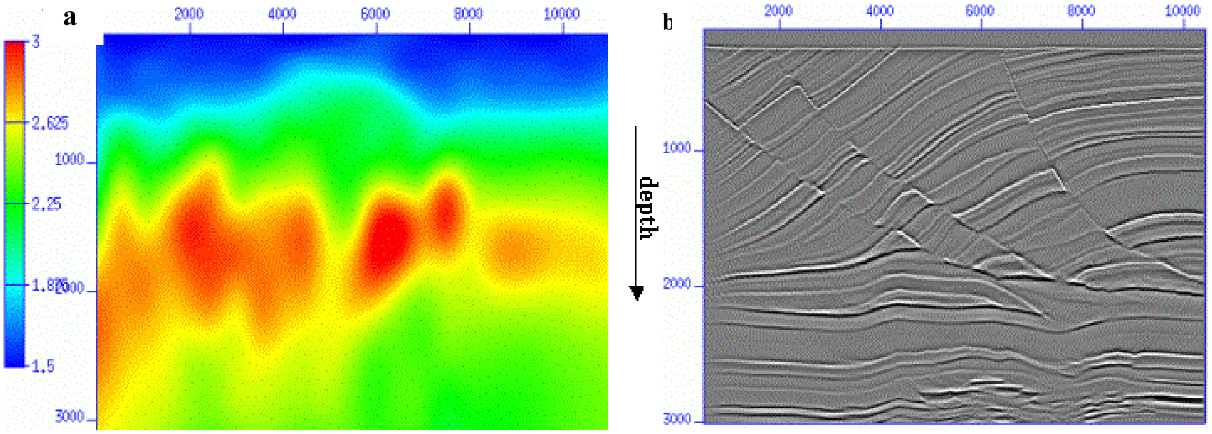

Figure 3: (a) velocity model obtained by poststack Stereotomography; (b) prestack depth migration using velocity model obtained by poststack Stereotomography

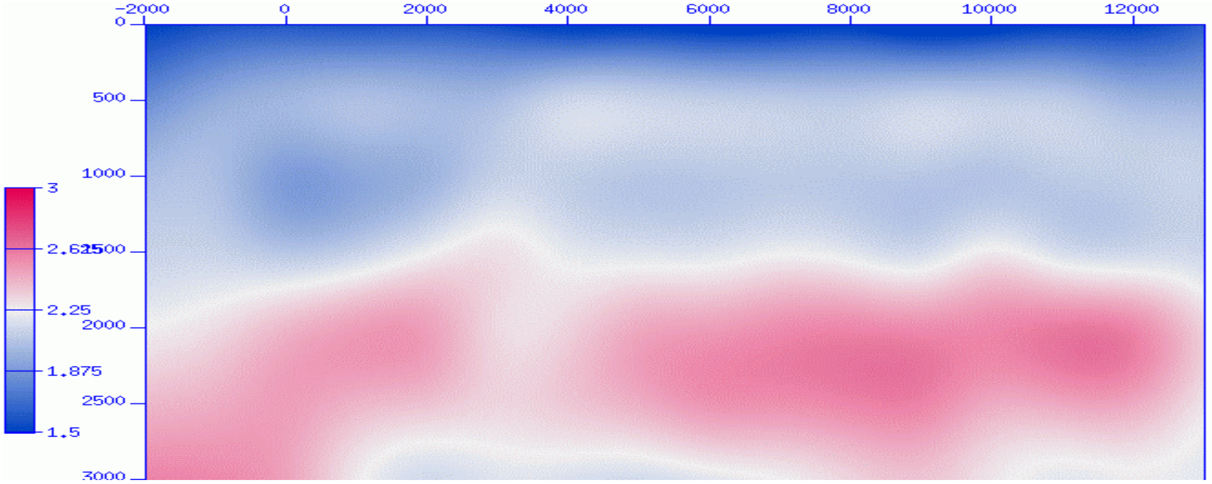

Figure 4: estimated velocity model on real data

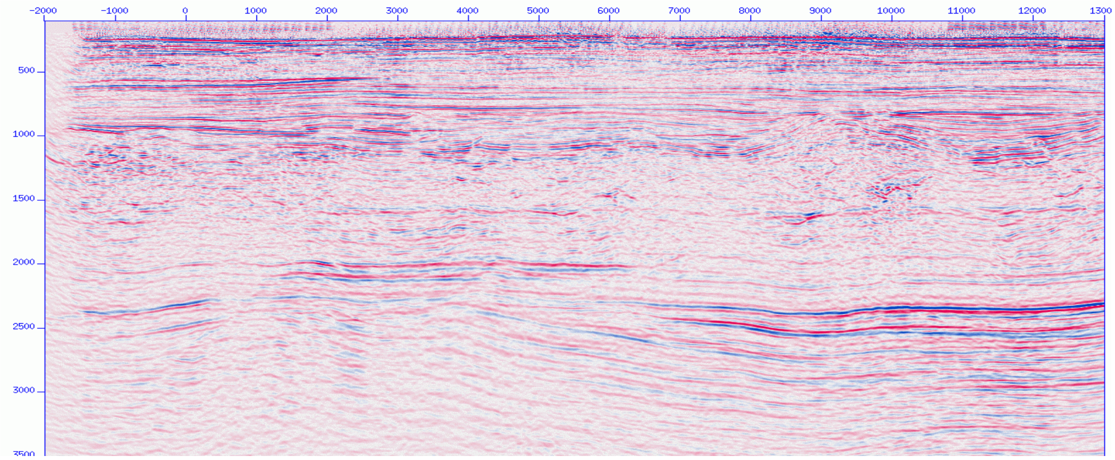

Figure 5: associated prestack depth migration.

Conclusion

We proposed a poststack version of Stereotomographic velocity inversion, when reliable information of zero offset times for locally coherent events is picked in poststack time domain. CRS method is an efficient tool for calculation an accurate zero-offset approximation and for estimation of wavefront parameters from prestack wavefield. Prestack traveltimes and slopes required for Stereotomography are computed from these wavefront parameters. Poststack Stereotomography provides a fast, robust and automatic way for velocity model construction in many practical cases and opens a way for Stereotomographic inversion in 3D case.

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