DDR technology of model based processing and interpretation of VSP data

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ABSTRACT

The ultimate goal of seismic data processing is a recovery of a model of an investigated medium. At the same time it is important to use some reference model of the media (particularly, velocity model) during processing and especially imaging procedures because only in this case one may expect to derive adequate results for further interpretation. At interpretation stage, during seismic image analysis it is possible to estimate the inconsistency of the model used and make appropriate corrections. These considerations lead to the concept of simultaneous iterative processing-interpretation of seismic data. DDR (Dynamic wave field Decomposition and velocity model Reconstruction) is the implementation of such concept for vertical seismic profiles data. DDR is an interactive tool of velocity model editing, ray tracing, wave field separation and joint imaging with the use of various wave types including multiples. The concept, general DDR processing workflow together with corresponding illustrations is presented.

INTRODUCTION

As a rule, the processing and interpretation of seismic data are divided in time and often are carried out by the different software packages. Thus the information about model is used not in complete volume, and some simplified approaches have to be applied.

Now most imaging procedures are based on ray-tracing and various migration transformations, but each of such methods separately has a number of serious disadvantages. Only parts of whole wave field, such as P or PS waves are used for imaging.

Besides in many cases strongly simplified models of environment (such as flat boundaries, absence of gradients of velocities etc.) are used which results in large errors in interpretation.

The first approach to the new technique of processing and interpretation of the VSP data in complex models consisting of adjacent system of arbitrary-non-uniform bodies with fragmentally regular borders is presented below.

The regular waves of various types and orders have to be consistently located and subtracted from an initial field and projected on the image with use of basic model. For subtraction the time graph and amplitudes calculated on initial model of environment are used within the framework of a ray-tracing method.

The obtained image can be used for correction of initial model, and this way is one of iterative steps to determine model which is adequate to interpreted wave field. Further we shall call this method as a method of Dynamic Decomposition and Reconstruction (DDR) (Tabakov et al., 2002).

SCHEME OF THE METHOD

The technology of VSP data processing by means of DDR technique consists of several procedures:

- construction of the first model approximation as a result of kinematical inversion of travel times and polarizations for visually correlated events in original data (Stepchenkov et al., 2005);
- the calculation of model wave from every bound is worked out for each visible event taking into account times, amplitudes and polarizations;
- the located wave amplitudes, multiplied by a P-wave normal-reflection factor, are subtracted from initial wave field and are projected to the points of scattering on the image. The waves of various types from the same point of boundary are stacked with weights proportional to their original amplitude. The process is repeated for all types of waves and all boundaries until all regular events are subtracted and projected on section. Not only primary waves, but also multiples may used in the process;

After imaging the basic model can be corrected and the process may be repeated until the image will correspond to model with necessary accuracy (Reshetnikov et al., 2003).

The technology of dynamic decomposition was realized as a software product. The interactive program has a double-window interface: the first window demonstrates real wave field, while the second – a model approach. The main idea is to extract useful information from the wave field and accordingly to it correct the model, tying it with the field. Therefore, it’s possible to solve the inverse problem of model parameters selection in iterative manner (boundaries geometry and geological bodies parameters are corrected).

The usage of this method becomes possible only in the presence of reference model of appropriate complexity. Therefore the first step should be construction of initial approximation, build upon the solution of inverse kinematic problems. Thus, the complete cycle of processing data includes the following steps:

- construction of initial model approximation by solution of inverse kinematic problem, input data for which is the wave field information;
- iterative specification of this approximation until the model is coordinated with initial wave field. Fig. 1 shows the scheme of DDR technology.

DIRECT PROBLEMS SOLVING

The problem of given wave characteristics calculation is to find the initial angles of the rays with given wave code, witch pass through the receivers. If these rays are found, it's possible to estimate the time of wave propagation and the amplitude by their trajectory. Therefore, the method allows deriving amplitudes, hodographs and polarization parameters of any wave type.

WAVE FORM DETECTION ALONG HODOGRAPH

The knowledge of hodograph, polarized wave parameters, and opportunity to separate the wave form along the hodograph, makes it possible to subtract the wave form from full wave field without interference influence. Thus, by sequential subtraction of all waves in decreasing amplitude order it's possible to get exact wavefield decomposition. Application of ray-path method of wave parameters calculation allows easy creation of images corresponding to subtracted wave as reflection points are defined at the ray-tracing stage.

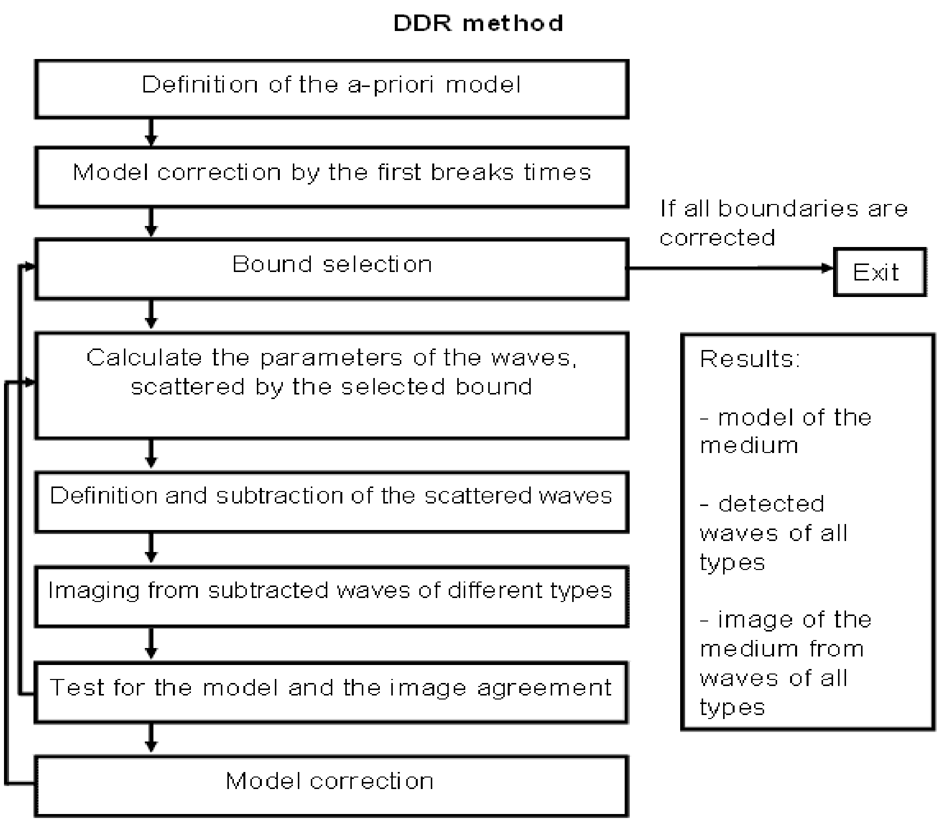

Fig. 1. Scheme of DDR Technology.

JOINT IMAGING OF THE MEDIA USING DIFFERENT TYPES OF WAVES

Depending on boundaries configuration, different parts of interfaces can be exposed by one or more type of waves. Obviously, all types of waves contain information about properties of the media. It means that in process of imaging of the media all available information should be used. It is also necessary for the derived solution to particularly include "one-wave imaging" case.

The way to calculate joint image is summing of the images from all types of waves. It is important to remember that all images dynamically correspond to different physical measures. Therefore images must be normalized before stacking. The normalization coefficient can be evaluated as

$$\gamma = \frac{1}{N} \frac{K_P^0}{K},$$

where:

K – reflection coefficient, calculated using reference model;

K_P^0 – normalized measure;

N – number of summed images.

Thus, for all boundaries of the model joint images can be calculated using all types of waves.

These images can be composed into one seismic section. In this section amplitudes correspond to the reflection characteristic of the media (Reshetnikov et al., 2004).

The method allows full seismic image constructing which represents the media by values of true reflection coefficient along normal to the boundaries. Fig. 2 and 3 presents the images for different types of waves and joint image of the boundary.

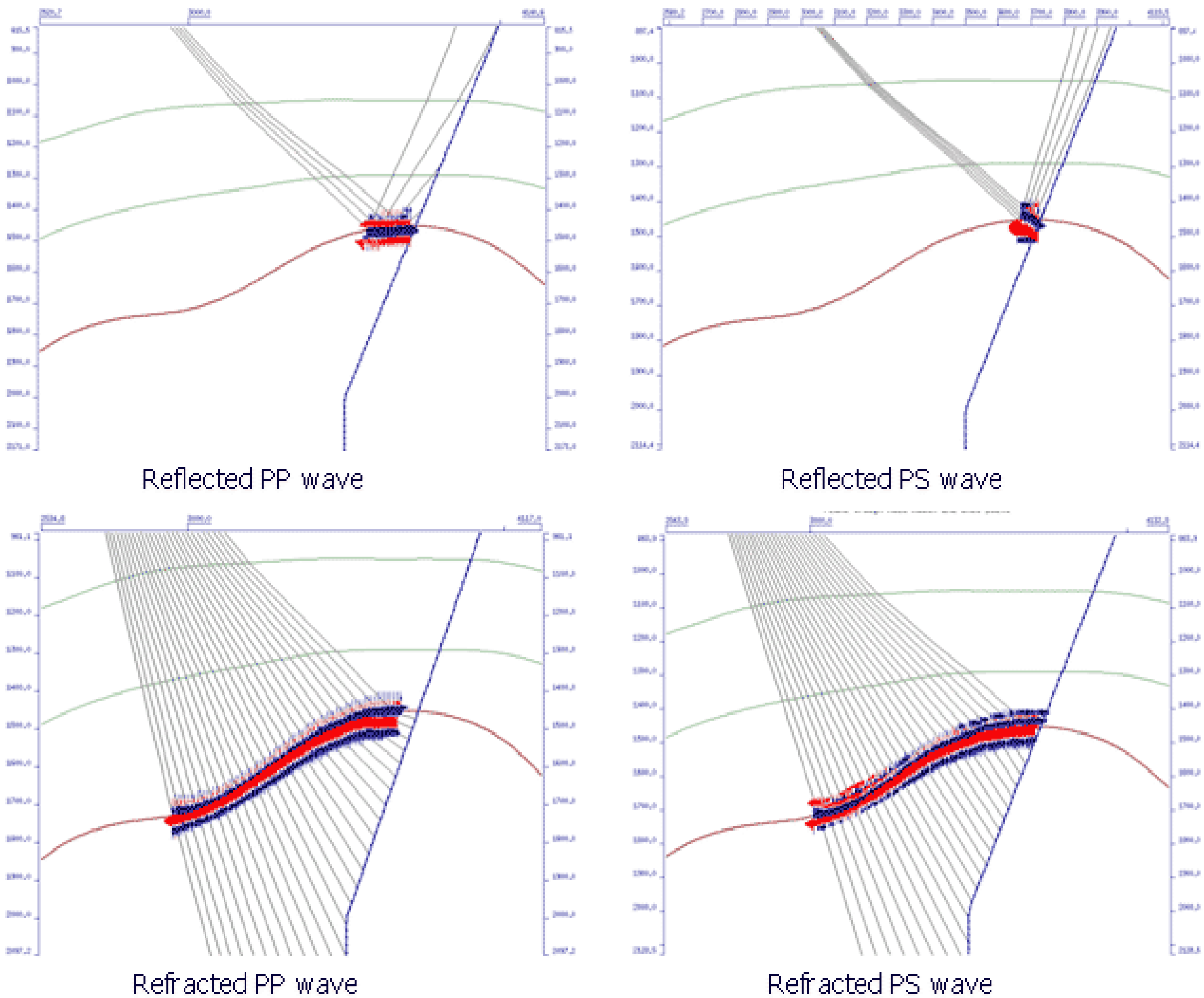

Fig. 2. Images for different types of waves

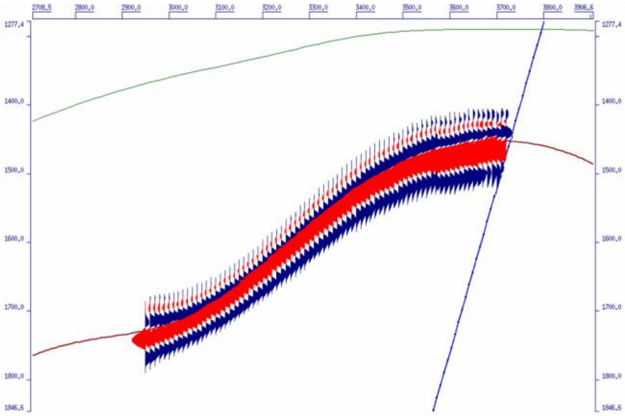

Fig. 3. Joint image of the boundary

MODEL CORRECTION

In case of variance between model and the field, calculated arrival times don't match the real field. Therefore some errors will occur during wave form extraction along calculated direction. The more the difference between current model approximation and reality is, the stronger are the errors. The critical idea of model correction is to amend bound geometry until there is good coincidence of calculated hodographs with the field (and good-quality bounds image correspondingly). It's necessary to take into account the obtained image and user's experience when model is being corrected. Figure 4 shows the image created under inexact and adjusted bound.

Initial approximation method (inverse problems) assumes that geometry of bounds is approximated by smooth spline functions. However real geological models may contain faults (or intersections of geological bodies bounds). The technology of construction and model correction allow to reveal different violations and improve the model, moving in amendments. Figures 5, 6 show the process of detection and inclusion of a fault into the model.

Figure 5 demonstrates hodograph calculated of initial plain bound in the model, which was obtained as inverse kinematic problem. It's obvious, there is one more wave in the base wave field with similar characteristics, but with displacing in the time. It might be said about shift break in the real bound. The form of both waves was picked out along received hodograph and image of plain bound was build up (figure 6a).

In this state it's possible to detect some violation and amend the model (figure 6b). After violation's inclusion each segment was considered as independent source of waves. Different segments waves of target bound were counted, and then their images were created (figure 6c). The resulting images are corresponding to geometry of the model, thus, obtained model is agreed to some accuracy with the initial model, to which the wave field was received.

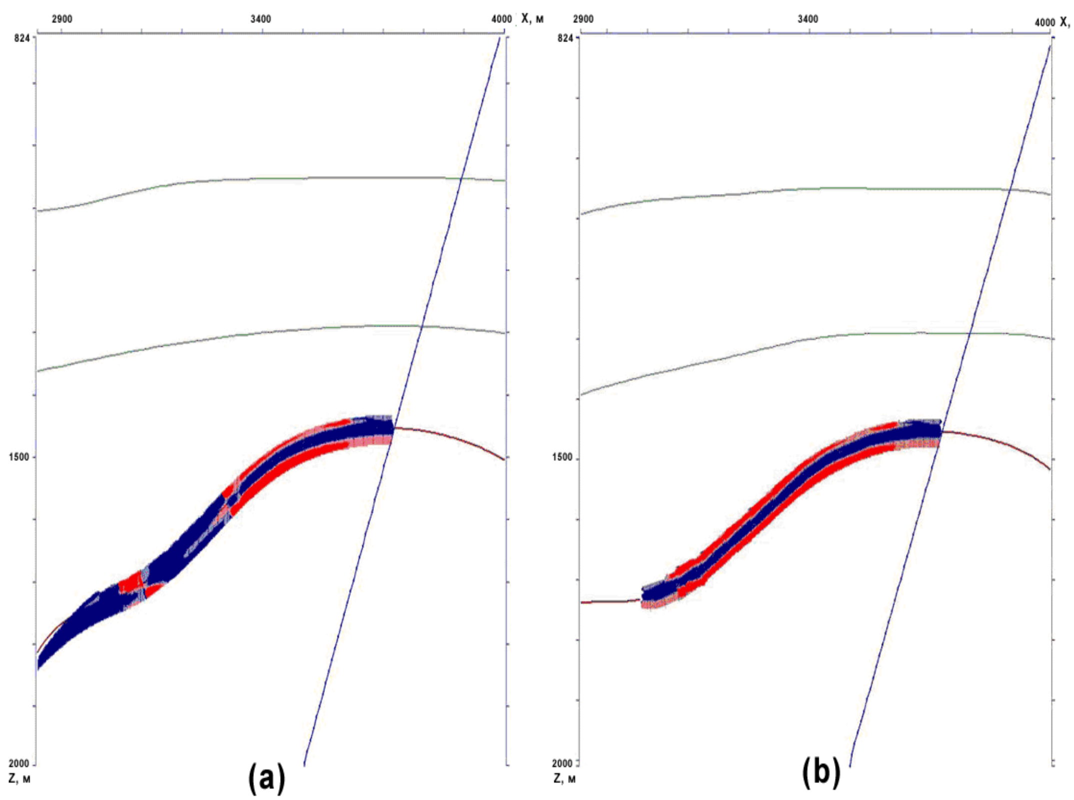

Fig. 4. Images created using inexact (a) and adjusted (b) model.

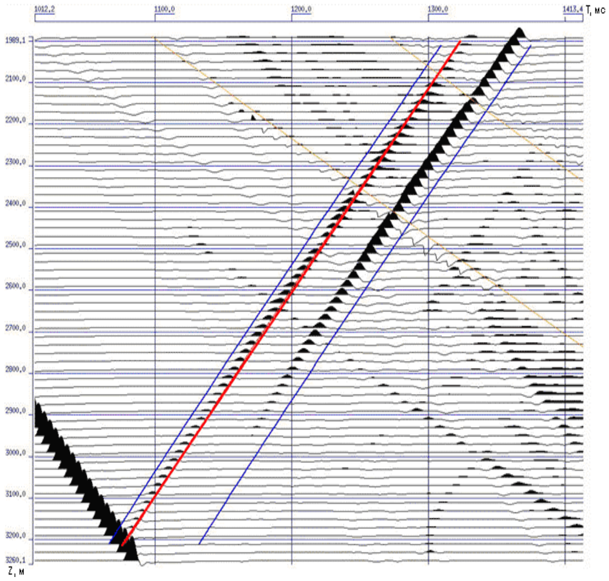

Fig. 5. Hodograph calculated for initial plain bound in the model.

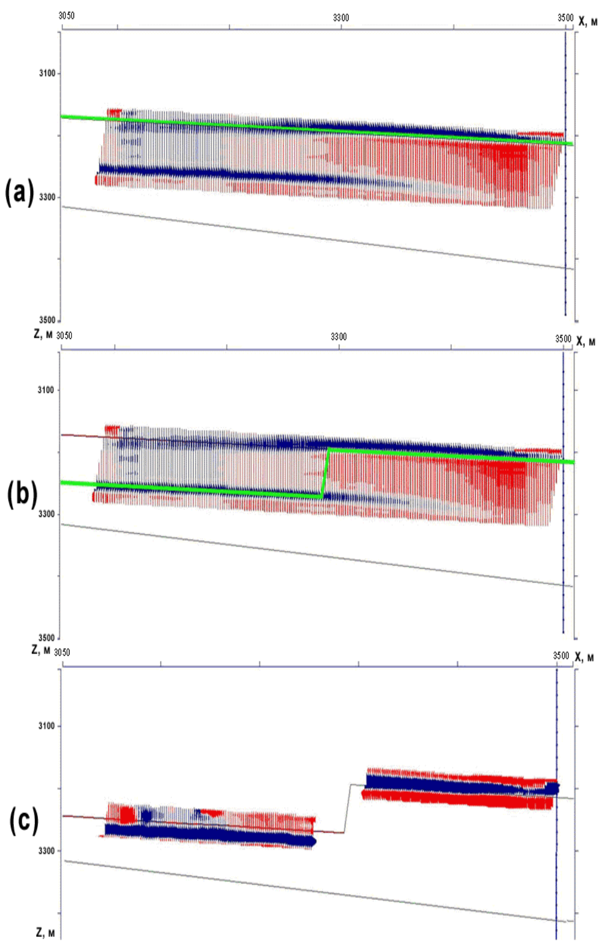

Fig. 6. Process of detection and inclusion of faults into the model.

APPLICATION EXAMPLE

Numerical experiment was carried out to illustrate the proposed concept. Based on a given velocity model synthetic wave field was computed by finite-difference method (fig. 7a). Then travel times of all primary reflected and transmitted waves were picked and depth marks of model interfaces were defined along the borehole (fig. 7b).

After that the procedure of kinematic inversion was implemented the derived velocity model was adjusted with the use of DDR techniques. Comparison of the resulting recovered model and original model is displayed in fig. 7, 8.

CONCLUSIONS

According to DDR procedures effective methods of description of free two-dimensional spheres and methods of ray computation in spheres of variable seismic velocity gradients were worked out. This technology allows to solve two-dimensional inverse problem for vector wave fields, combining and improving both processing (wave vector selection) and image sphere building.

This method is realized as complete technological consequence. It is a commercial software product, being tested up to this time.

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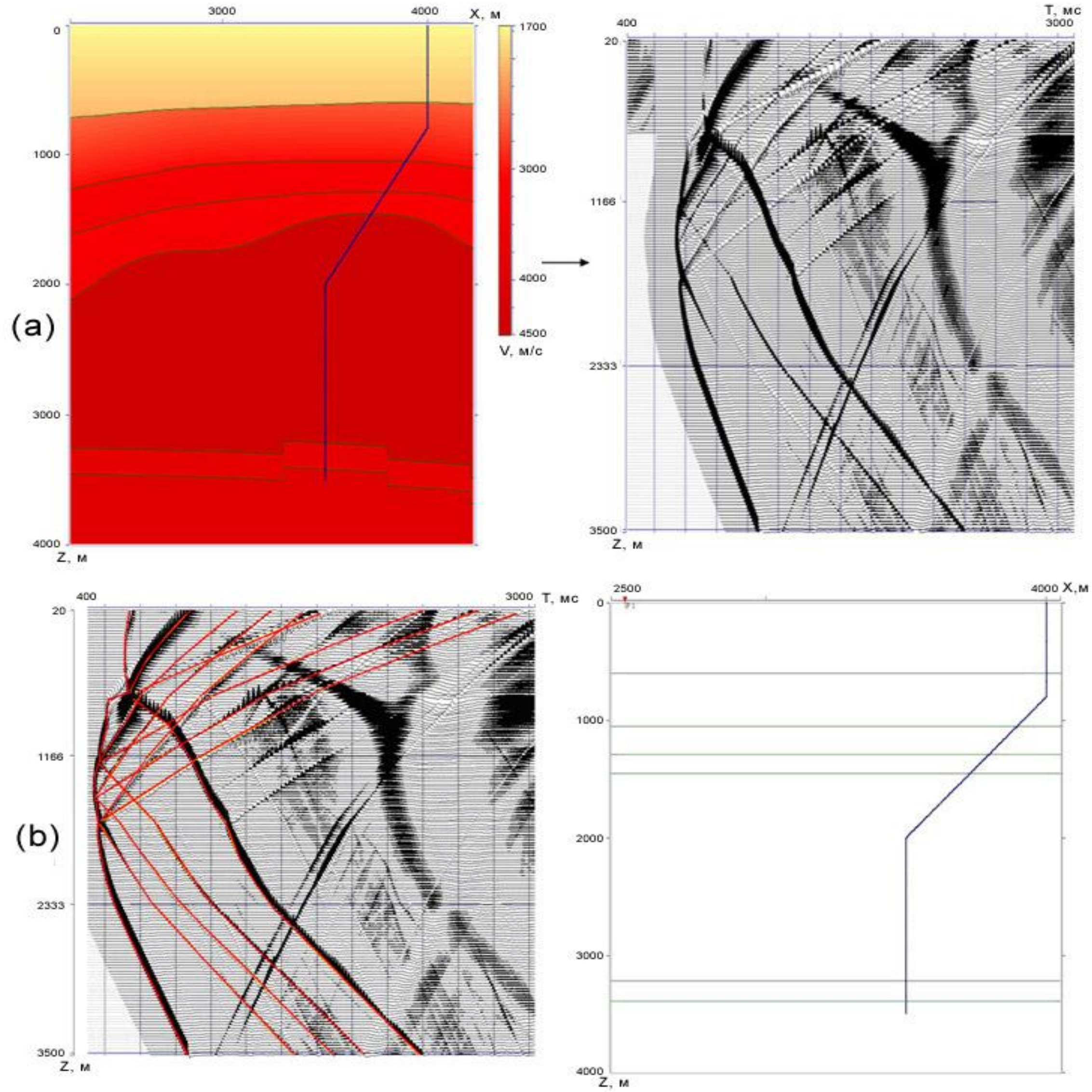

Fig. 7. (a) Original velocity model and synthetic wave field. (b) Travel times of all primary reflected and penetrated waves and model interfaces position on the borehole.

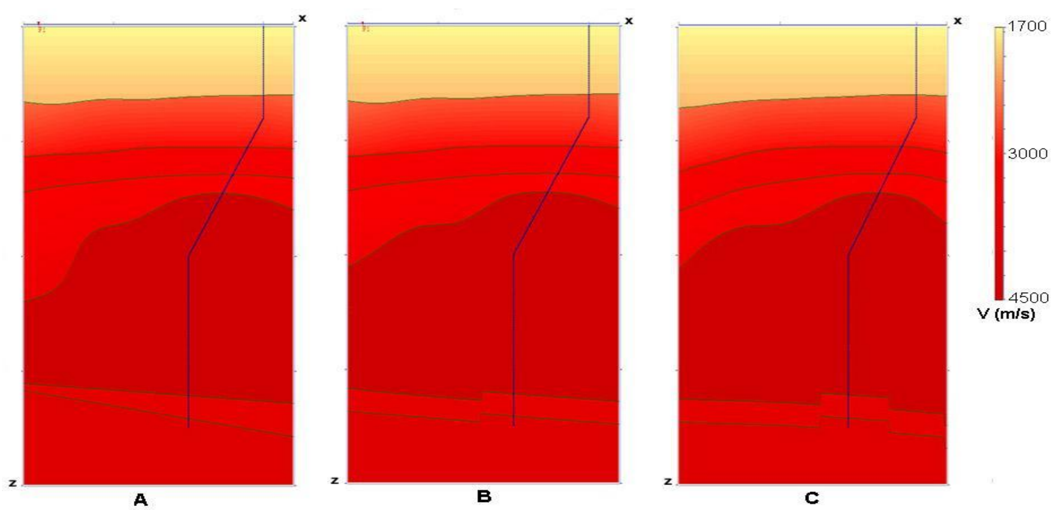

Fig. 8. Result of inverse kinematic problem (a), resulting recovered model (b) and original model (c)

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