TIME-DEPENDENT SCATTERING IN REVERSE TIME HOLOGRAPHY METHOD

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Summary

The time-dependent scattering model for Reverse Time Holography method is proposed (called Vector Scattering Pattern). Allowing a scattering dependent from time, a new features for the two global subset of Vector Domain Common Image Gather - hard and soft, concerning reverse time, were obtained. It is shown that the VSP analysis is the good tool for the detail seismic attributes estimation. The mapping of productive horizons and searching a sweet spot using only one attribute of RTH method - RTH-velocity is presented.

Time-dependent Scattering in Reverse Time Holography method

Introduction

The technique of integration by parts underlies the most important mathematical approaches, such as the definition of Lagrange conjugate operators, Bayes' formulas, conjugate problem statements for differential equations etc. As it turned out, in physics, conjugate processes also underlie a number of known technologies such as time-reversal mirror for laser beam (Zel'dovich et.al.,1972) and time-reversed acoustics (Fink, 1997). In seismic prospecting, conjugate formulations for the wave equation are the basis of the well-known Reverse Time Migration (RTM) method (Baysal et.al., 1983; McMechan, 1983). In Full Wave Inversion method, conjugate mathematical formulation is used to calculate the Frechet derivative while minimizing misfit functional (Tarantola, 1984; Virieux, at.al., 2009). Alekseev and Erokhin, 1989 for the first time, mentioned the close connection between the essence of the conjugate approach for Simultaneous Joint Inversion (SJI) method, proposed by the authors and of time-reversal mirror for laser beam. They also marked the mathematical similarity of the SJI approach with the optimal control problem in ecology (Marchuk, 1976). In the same paper, the convergence of JSI solution on some weakly compact set and an increase in the stability of the solution on it were constructively proved.

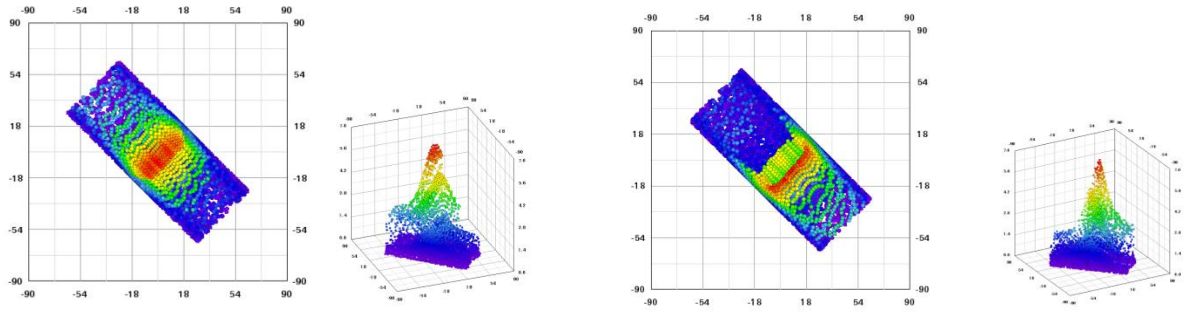
In the papers Erokhin, 2019 a new Reverse Time Holography (RTH) method is proposed for design seismic attributes. This method combines two approaches: reversal of a wave in time based on the conjugate problem for the acoustic equation and two-beam interferometry, similar to that used in optical holography (Gabor, 1947). The data processing consists of two stages: decomposition and synthesis (Erokhin et.al., 2020). Decomposition stage includes a highly accurate vector decomposition of time-reversed seismic information which is recorded at the surface, for example by CDP method. At this stage, as in optical holography, a certain reference wave is also used for two-beam interferometry. The received information about the interference of the reference wave and time-reversed wave forms a set of vector pairs, which is called Vector Domain Common Image Gathers (VDCIG), (Erokhin et.al., 2018a). This digital dataset is similar a photographic plate for optical holography, on which the amplitudes and phases of two-beam interference are recorded. The second stage of RTH (synthesis) consists in statistical evaluation of parameters of the multidimensional random VDCIG distribution in order to obtaining the necessary seismic attributes. It turns out that such a formal mathematical approach makes it possible to construct by RTH method not only all known seismic attributes, but also to obtain much of new ones (Erokhin, 2019).

In this paper the important aspect of the RTH synthesis stage – an analyzing of space-time structure of scattering via VDCIG dataset is discussed. Such 4D analysis (three angles and time) of scattered wave was called by Vector Scattering Pattern – VSP. Allowing the scattering dependent from time a new features for the two global VDCIG subset, concerning reverse time, were obtained.

Method

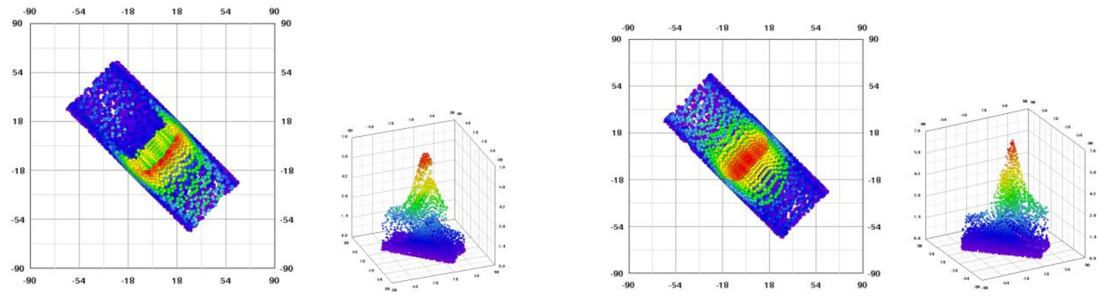
The RTH method is conceptually based on the assumption that the basis for attributed designing is the ability of each medium point to scatter the incident wave. It is assumed that the space-time anisotropy of scattering at a point carries full information about the property of the medium at a given point. In traditional seismic exploration, focused on strong reflective boundaries, which in their essence are nothing but in-phase scattering on it, typical models of the medium are often considered, consisting of layers with different impedances in them. In this case, at the layers boundary the impedance changes can be both in the positive side (hard reflection) and in the negative side (soft reflection). We take the same principle as the basis for the classification of the type of scattering for VDCIG but using also time characteristic of scattering. We also divide all events of VDCIG dataset having a random nature into events with scattering according to the Hard Vector Scattering Pattern (HardVSP) and the Soft Vector Scattering Pattern (SoftVSP) one based on the behavior of the vectors of the incident wave and the scattered in time. It turns out that the distinctive feature, by which these subsets can be divided, as in the case of soft reflections, is the fast phase change at 180 degree of the scattering vector for

SoftVSP case. This is exactly the same as the time reversal effect (Zel'dovich et.al.,1972, Fink, 1997). Of course, there are no pure hard scattering or soft scattering in nature. However, the relationship between these two types of Scattering Pattern allows, nevertheless, building a convenient classification of VDCIG events. Such VDCIG classification allows analyzing more detail the properties of the medium through the HardVSP and SoftVSP sub-attributes of the main seismic attributes. Indeed, Figs. 1, 2 shows the distributions of the amplitudes of the waves scattered at the point of diffraction for times from - 80 ms to +80 ms relative to the arrival time. Sampling time here is 0.4ms. We are considering 2D model of the medium. The horizontal and vertical axes are the Dip Angle and Opening Angle (Erokhin et. al., 2017, 2018b). So, for 2D the VSP is depended from two angles and time. For 3D the VSP will be dependent from three angles and time. The values of the scattering amplitudes are presented separately for events satisfying the conditions HardVSP (Figs. 1a and 2a) and the conditions SoftVSP (Figs. 1b and 2b). Diffraction is modeled by a jump in velocity at the points under consideration from the background velocity of 3 km/s up to 3.1 km/s and down to 2.9 km/s. The number of sources is 41, the step between the sources is 50 m, the step between the receivers is 25 m, the receivers offset is 2000 m. The size of the area is 2x2 km. The size of the RTH pixel is 25x5 m. The diffractor is located in the center of the region at a depth of 1 km. Ricker's pulse frequency - 40 Hz, time sampling - 1 ms.



a b

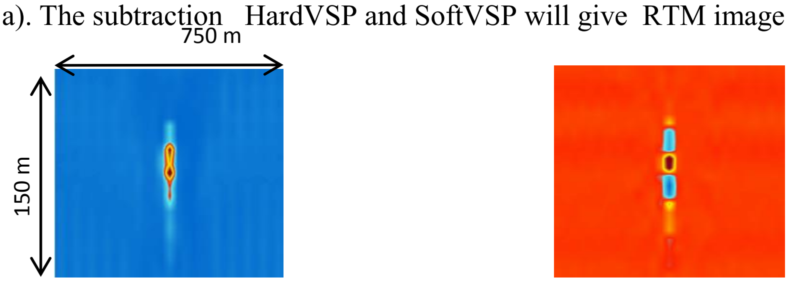
***Figure 1** HardVSP angle scattering distribution, diffractor velocity 3.1 km/s (a), 2.9 km/s (b)*



a b

***Figure 2** SoftVSP angle scattering distribution, diffractor velocity 3.1 km/s (a), 2.9 km/s (b)*

Using the HardVSP and SoftVSP sub-attributes we can quite simply construct well-known seismic attributes. So, for example the sum of HardVSP and SoftVSP will give the Relative Impedance (Fig. 3a). The subtraction HardVSP and SoftVSP will give RTM image (Fig. 3b).

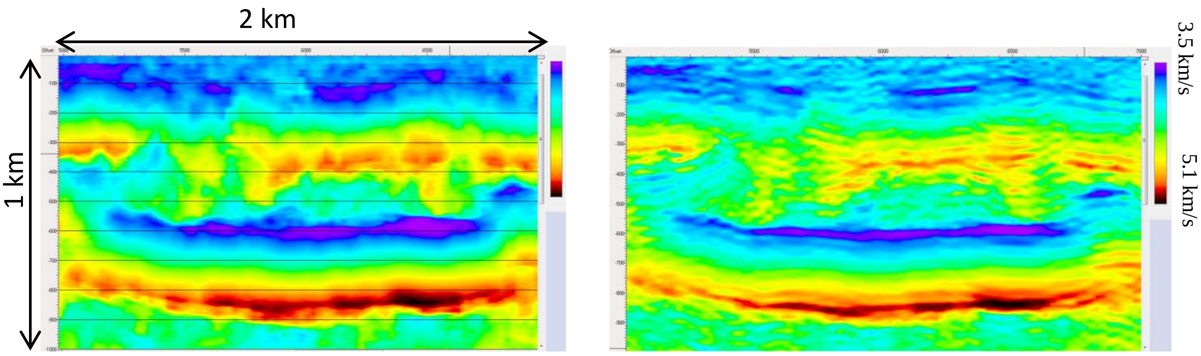


a b

Figure 3 *HardVSP+SoftVSP - Relative Impedance (a), HardVSP-SoftVSP - Depth Migration (b). Diffractor velocity 3.1 km/s .*

Examples

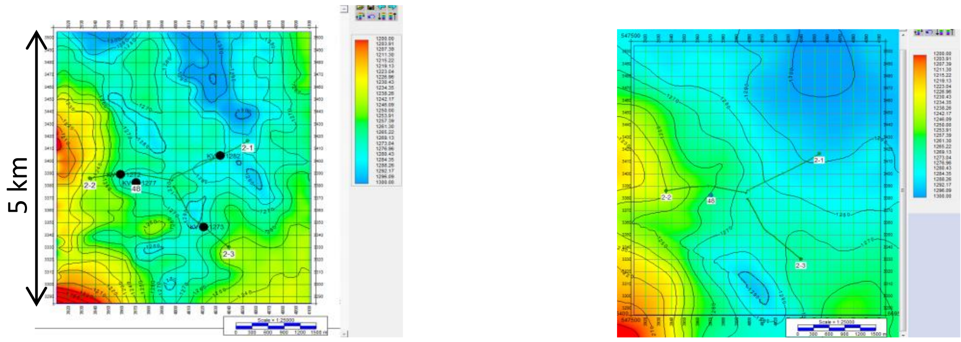
One of the most informative attributes which can be obtained by the RTH method is the RTH-velocity. Velocity is estimated by the deviation the seismic arrival time to a given point of medium from the prognostic time, which is calculated based on the initial velocity model (Erokhin et. Al., 2020). Figure 4 shows the comparison of the two velocity sections. The typical RTH-velocity is shown in Fig. 4a. Fig. 4b demonstrates the velocity built only on the HardVSP subset from VDCIG dataset. It is seems that the HardVSP RTH-velocity has a higher depth resolution. The pixel size in which the RTH-velocity is estimated is 25x5 meters. The SoftVSP velocity attribute is shifted 30m up.



a b

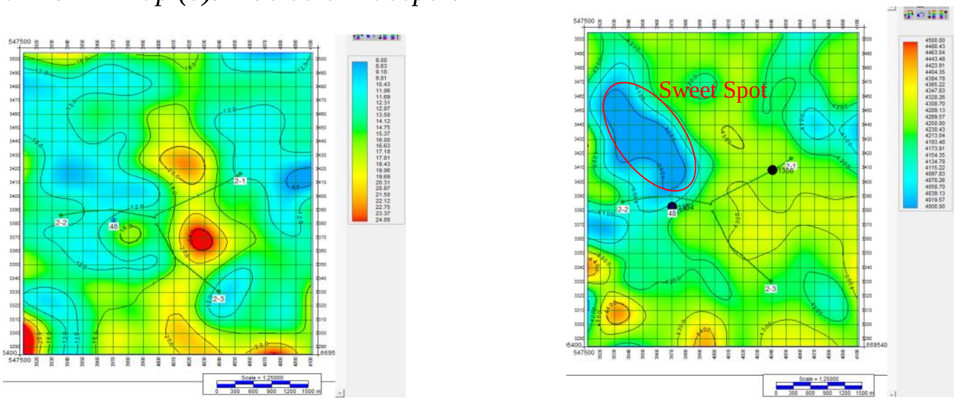
Figure 4 *RTH-velocity (a), HardVSP RTH-velocity (b)*

RTH approach allows us also to mapping productive horizons (Fig. 5) and to estimate thickness and perspective direction for horizontal drilling inside the horizons (Fig.6). The depths discrepancy the RTH mapping with the well inclinometry (black dots in Fig 5a) is not more than 2 meters. 3D voxel size is 12.5x12.5x2.5 meters.



a b

Figure 5 *Comparison of structural map constructed by velocity-based RTH approach (a) with the conventional PSDM map (b). Blue color –deeper.*



a b

***Figure 6** Velocity-based RTH mapping the productive horizon. Thickness map, meters (a) and RTH-velocity map, m/s (b). Blue color – small thickness and low velocity (Sweet Spot- red ellipse).*

Conclusions

The time-dependent scattering model for RTH's synthesis of seismic attributes is proposed (Vector Scattering Pattern). Allowing a scattering dependent from time a new features for a two global VDCIG subset - hard and soft, were obtained. It is shown that the HardVSP/SoftVSP analysis is the good tool for the detail seismic attributes estimation. The mapping of productive horizons and searching a sweet spot using only RTH-velocity is presented.

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