Геомодель

2023

Санкт-Петербург

10-я международная конференции

Геонауки: время перемен, время перспектив

17–20 апреля 2023 г. | Санкт-Петербург, Россия

ГАЗПРОМ НЕФТЬ

Extra wideband processing and interpretation of VSP data by High Definition Seismic technology (HDS)

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Introduction

High Definition Seismic (HDS) – is a complex of software, hardware and technologies including artificial intelligence, providing the best available results of processing seismic data in most wide spectrum band with high level of noises.

Velocity model have to be calculated from first break signature and combined with sonic and density logs to obtain detailed P and S velocities and density models.

The main strategy in VSP HDS processing is iterative analysis of vector wavefields combined with cascade prediction and spike deconvolution. On each step every type of regular waves and noises is detected and subtracted, producing set of separated data, which may provide the same input mixed wavefield after stacking the components. So we can call the technology iterative and additive.

Many iterations of wavefields splitting provide almost perfect separation of components. Original POLYCOR algorithm assure high quality of components distinguishing. These procedures are applied to raw data and to deconvolved ones on every step of deconvolution cascade.

In presented technology components of wave fields can be onefold downgoing (dp, ds) and upgoing (dpup, dpus) waves, full downgoing multiples (dpupdp, dpupds), any regular events, diffracted for example, and noises.

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Introduction (continued)

Possibility of extra wide (0–300 Hz) frequency band is confirmed by processing of real VSP data. Infra law (0-3 Hz) frequencies can`t be extracted from wavefields and have to be replaced from model. So information 1-300 Hz means 8+ octaves versus usual 2.5-4 octaves (for example 8-128 Hz) can be extracted from VSP data.

Processing results are checked by comparison of inverted reflectivity with log data. Then reflectivity have to be compared with corresponding trace of surface seismic. Accuracy of VSP to log and Surface Seismic (SS) to log by VSP is first units of meters. Zero-phase phase shift and deconvolution SS to VSP is available.

High resolution and s/n ratio make it possible to determine anisotropy related to vertical fractures and dips and azimuths of reflecting layers.

Taking into account relative complexity of HDS processing, application of Intellectual Robot (IR) to replace operator in many iterative operations becomes almost necessary. IR concept is to replace intellectual actions of operator: Analysis of data, Decision about next procedure, Performance of the procedure, Estimation of results (ADPE) and so on. IR ADPE is fully coupled including database with interactive chain means any step can be performed either automatically or interactively.

Next slide shows comparison of raw VSP wavefield and after HDS processing. Further demonstrated are intermediate results of iterative separation of regular waves and extraction of extremely high level noises after severe cascade deconvolution.

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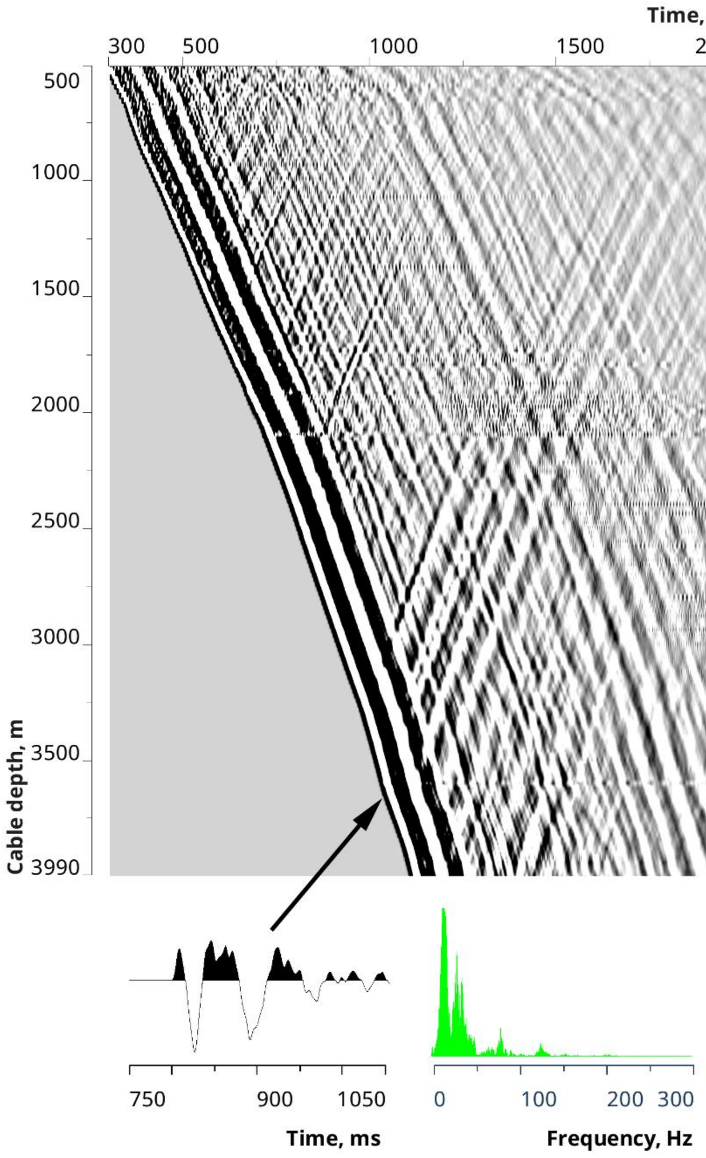
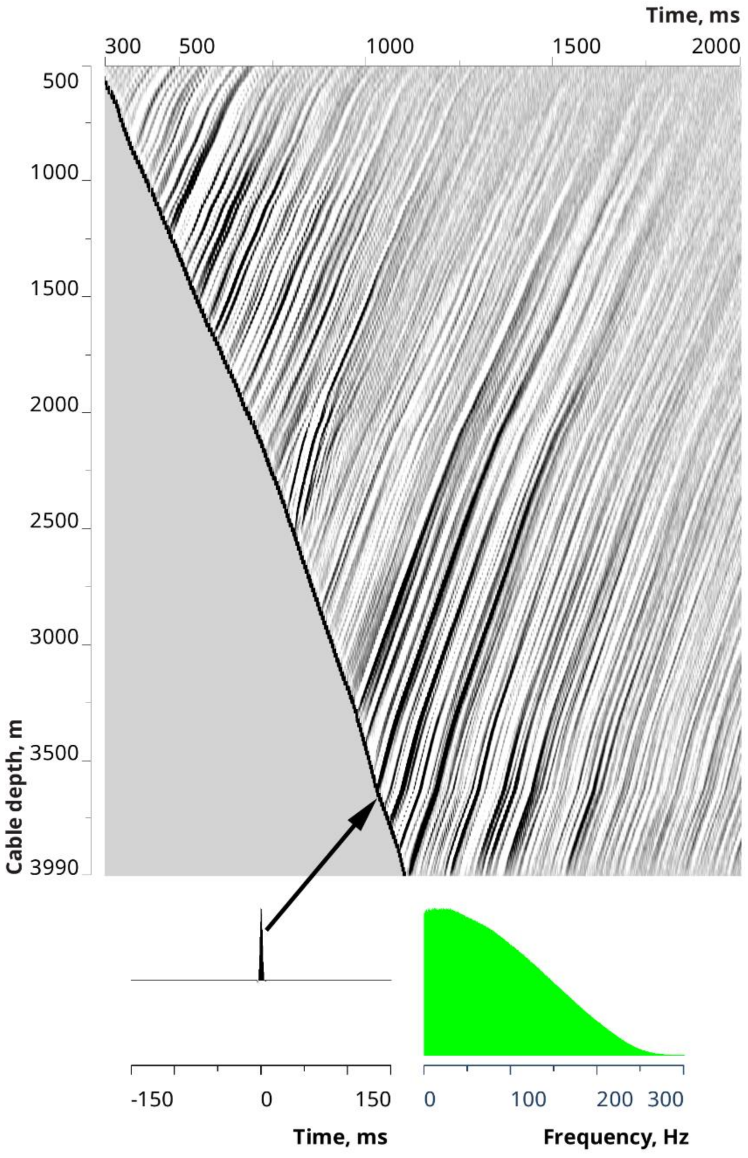
Fragments of raw wavefields and processed by HDS technology

Raw wavefield



Processed by HDS (direct and upgoing pressure waves)



Main steps of processing by HDS

1. Preprocessing.
 1.1. Estimation and subtraction of noises before first breaks.
 1.2. Correction of times and signatures.
 1.3. Estimation of polarization parameters, rotation to PRT system.
2. Kinematic processing.
 2.1. Estimation of layers and velocity model by VSP signatures near first breaks of offset VSP and LOG data.
 2.2. Calculation of common velocity model and anisotropies by joint optimization of all offsets.
3. Selection of individual useful waves and noises by iterative refinement and subtraction.
4. Prediction deconvolution.
5. Spike deconvolution by downgoing wave.
6. Tying up of LOGs, VSP and surface seismic.
7. Prediction of acoustic impedances and velocities beneath the bottom of hole.
8. Additional prospects of HDS.
 8.1. Estimation of shear waves anisotropy, coupled with vertical fracturing.
 8.2. Estimation of dips and azimuths of reflecting boundaries.
9. Automatic processing using AI.

1. Preprocessing

1.1. If there are deviations of zero line minimum phase HF filtration can be applied. Intensive HF noises can be preliminary weakened by filtration 0–0,6 * 1/2 dt.

1.2. Correction of times by reference geophone.

1.3. Estimation and subtraction of resonances.

1.4. Automatic preliminary estimation of first breaks.

1.5. Estimation, extrapolation and subtraction of noises Before First Breaks (BFB).

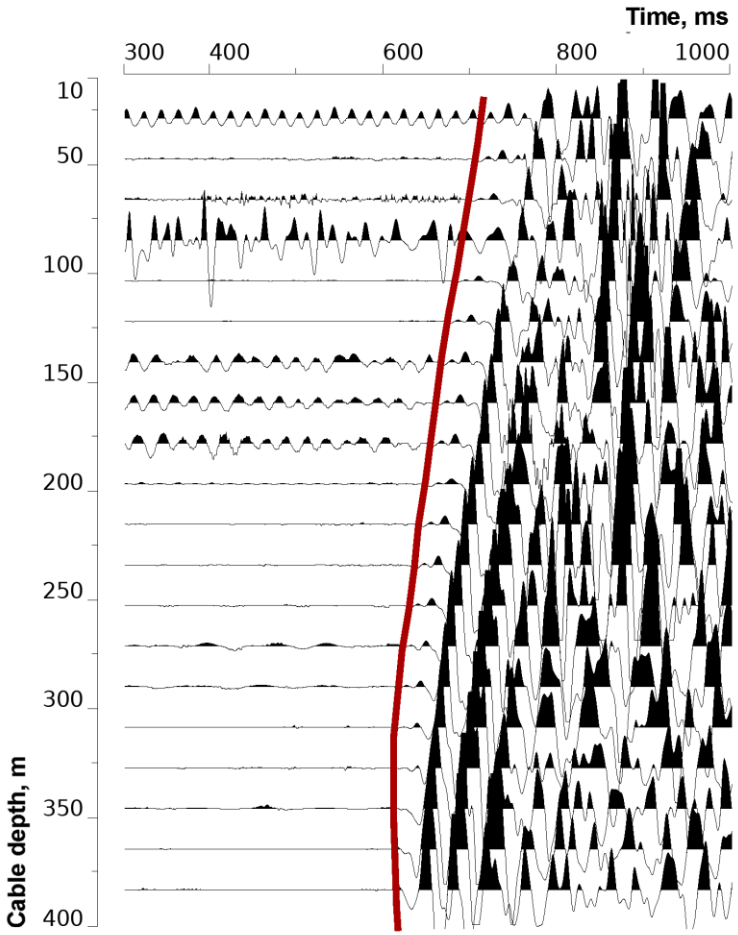
1.6. Refinement of FB, calculation and refinement of polarization parameters.

1.7. Correction of signatures to the most resolving.

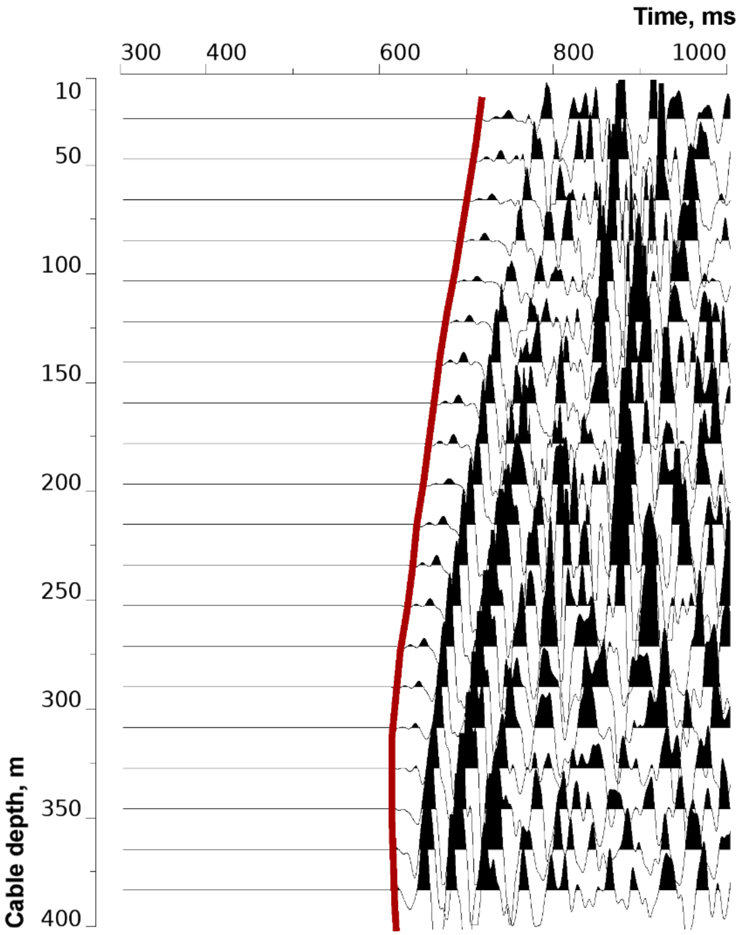
1.8. Rotation to PRT system.

Next slides show results of preliminary processing.

1.5. Estimation and subtraction of noises Before First Breaks

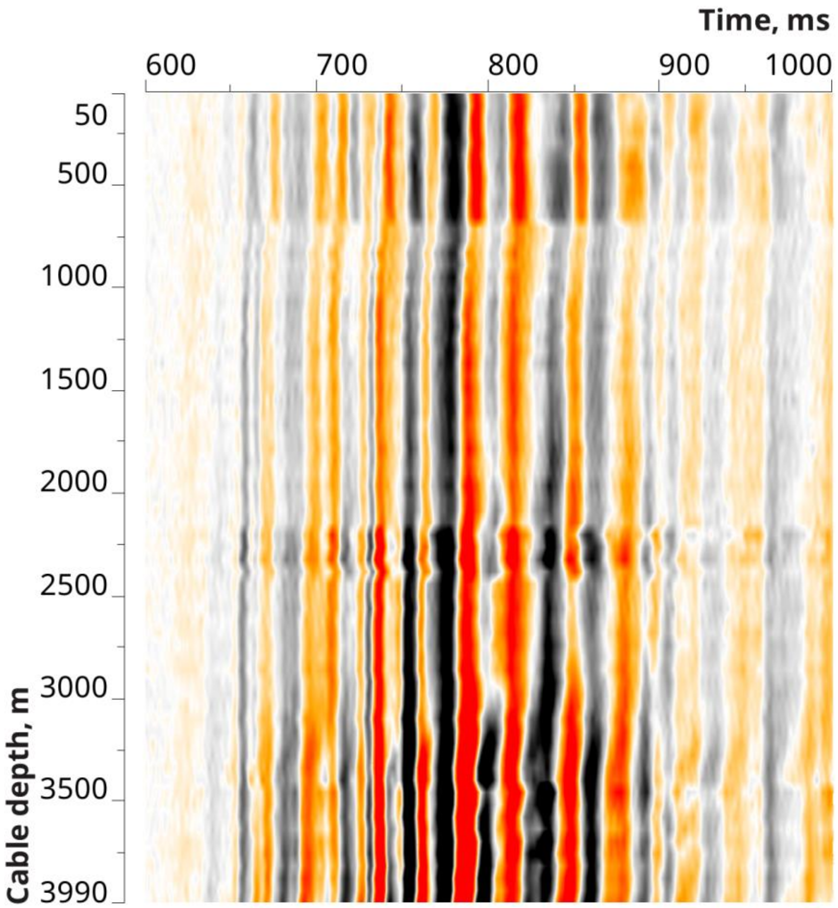


Raw wavefield (vertical component)

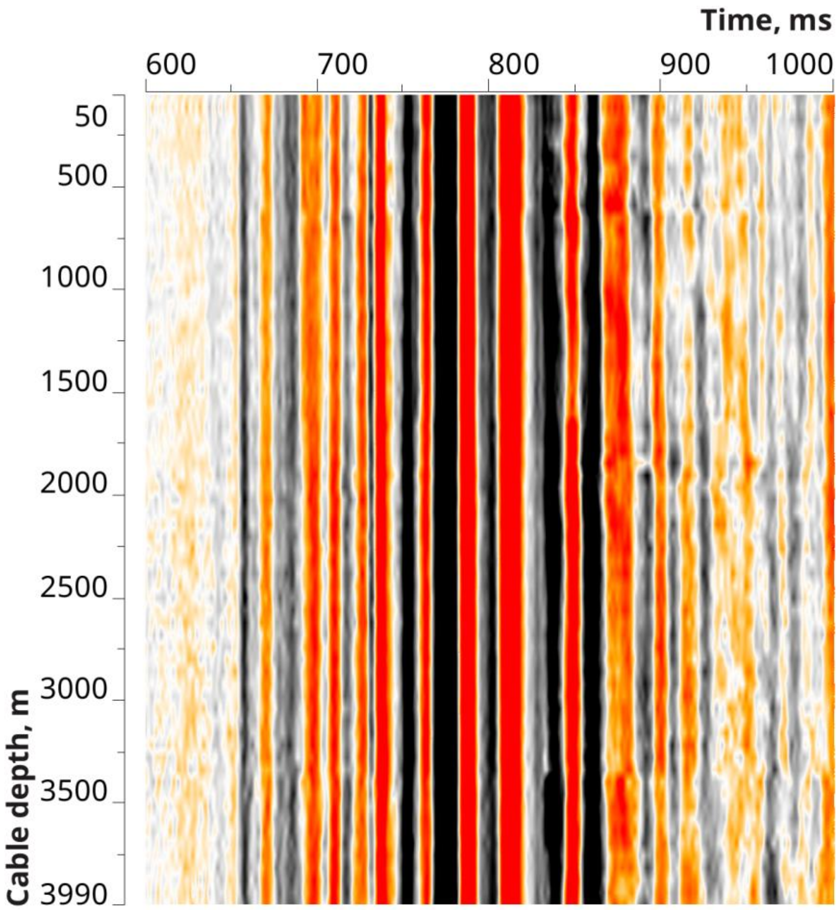


Raw wavefield after subtraction of noises

1.2. Correction of times and signatures by reference geophone. Reference geophone on a surface.

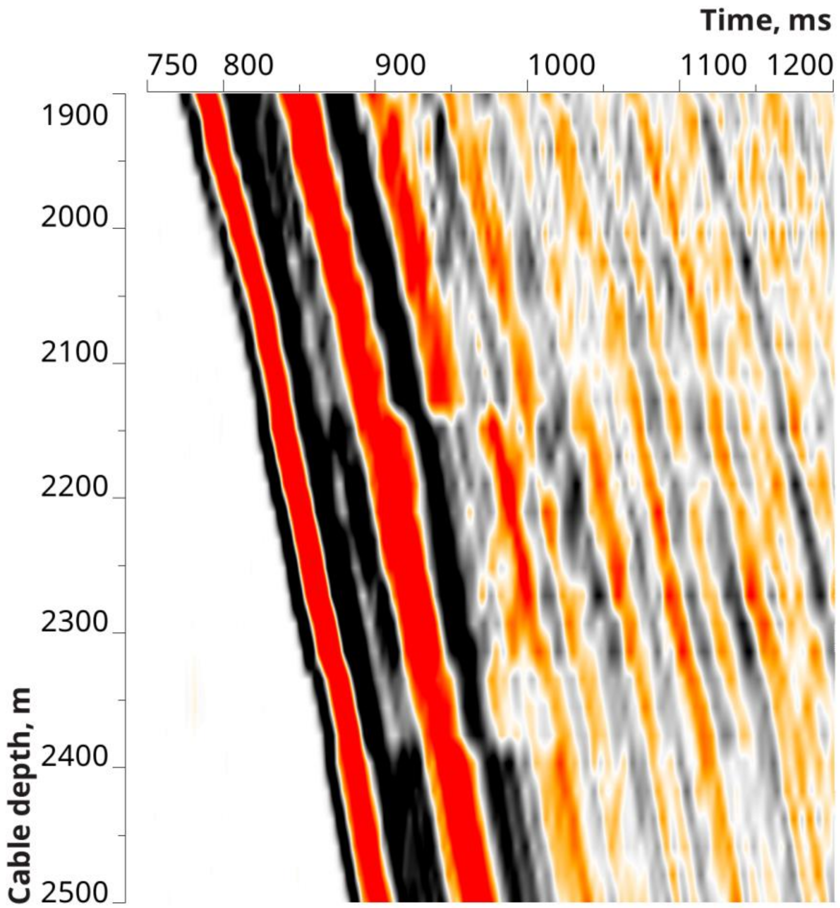


Before correction

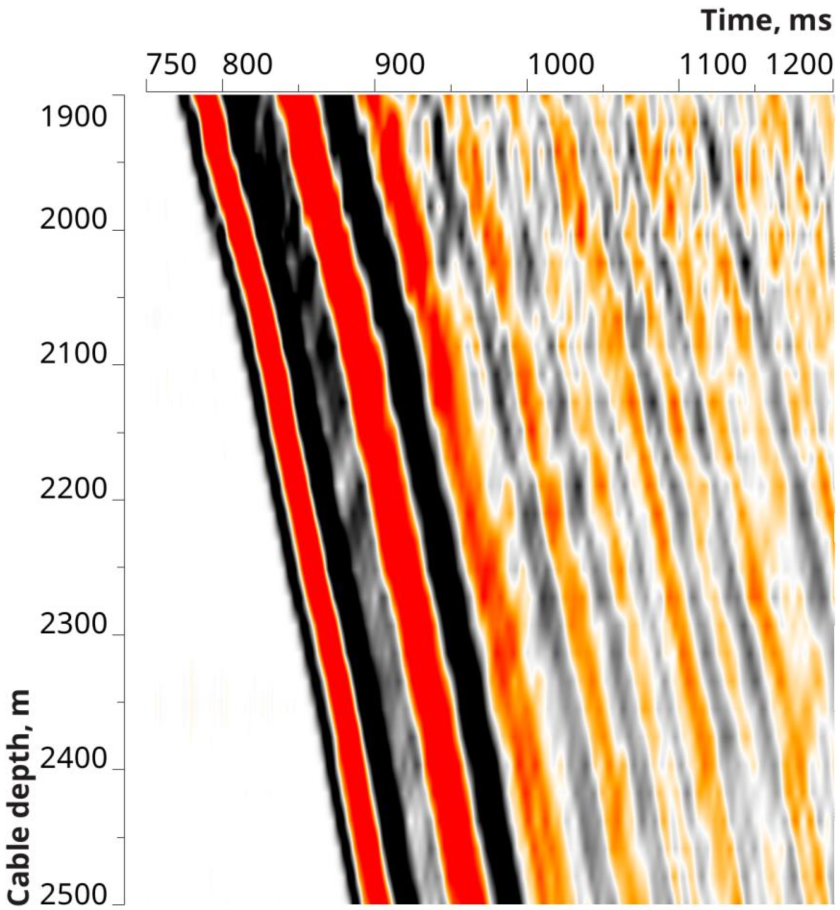


After correction

1.7. Correction of times and signatures by reference geophone. Reference geophone on a surface. Downhole VSP records.

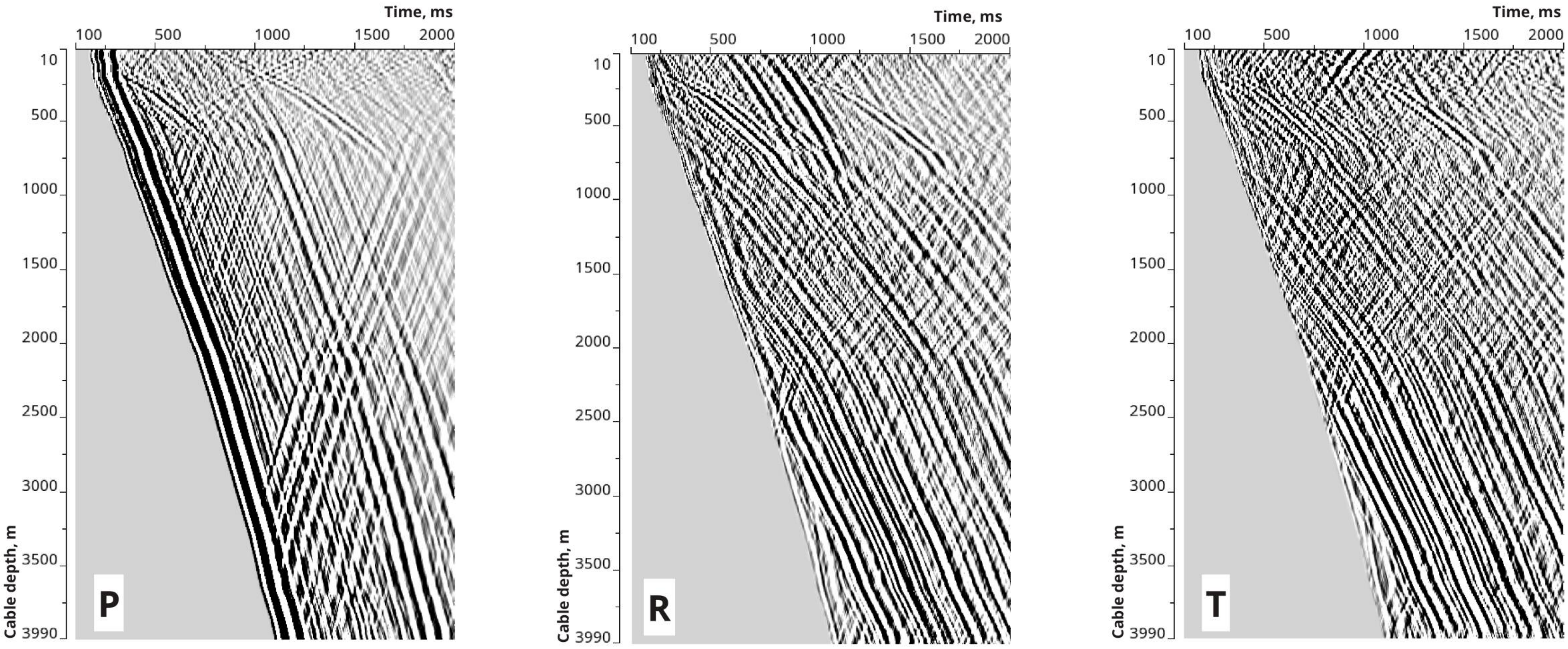


Before correction



After correction

1.8. Rotation of vecfor VSP wavefield to PRT coordinate system



2. Kinematic processing

2.1. Estimation of layer velocities.

Time graph of first zero crossing shifted to first breaks in the upper part of FB assumed taking into account velocities dispersion and absorption. Then layer velocities are estimated by optimization procedure.

2.2. Estimation of static shifts and anisotropies for each SP providing best fitting to all SP made by global optimization.

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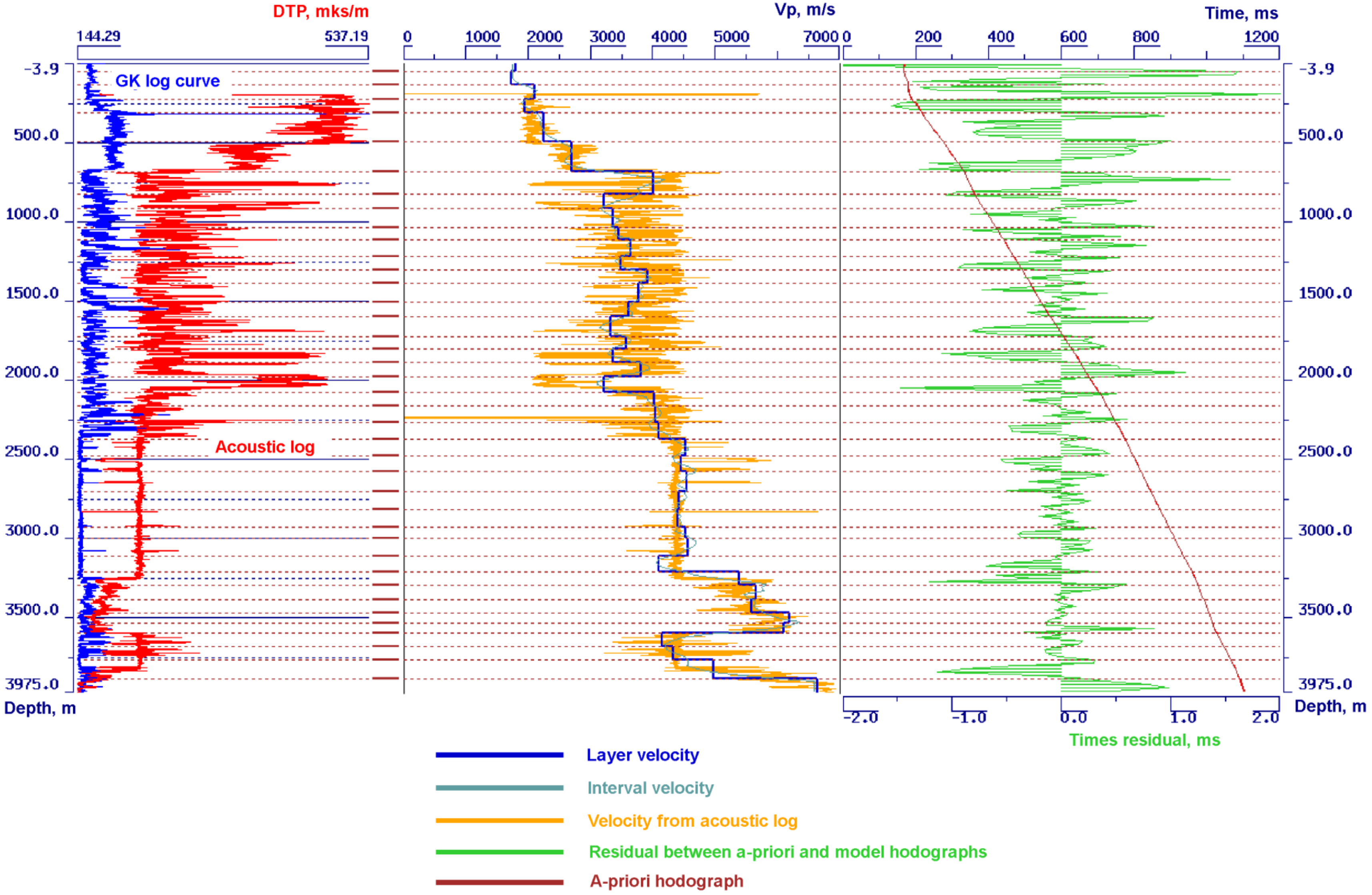
2.1. Detection of layers from FB hodograph with the use of LOGs and interval velocities by optimised inversion



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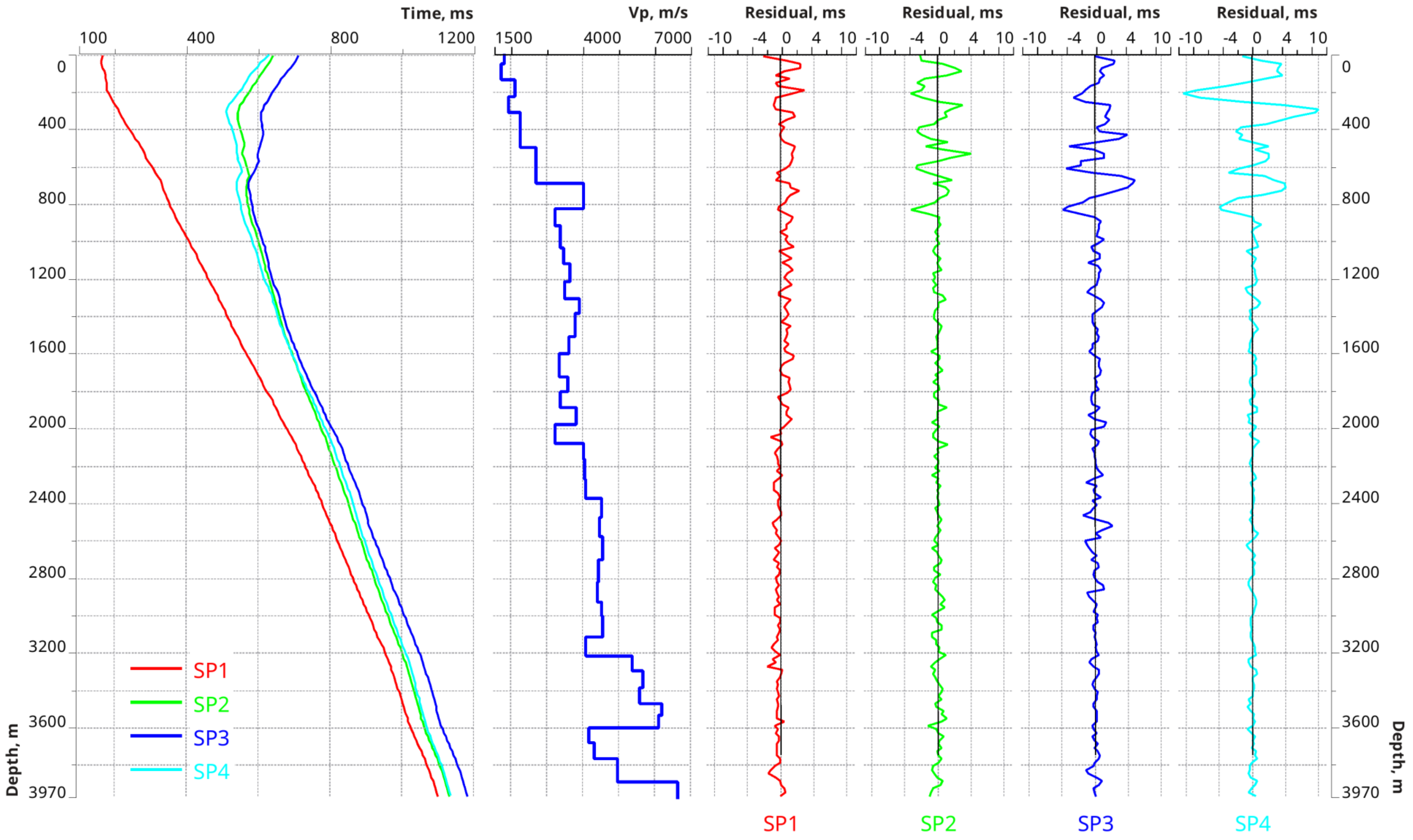
2.2. Determination of TLA anizotropy and individual SP statics by joint optimization of hodographs for all SP



Static shifts:
-13 ms for SP2,
-6 ms for SP3,
-5 ms for SP4.

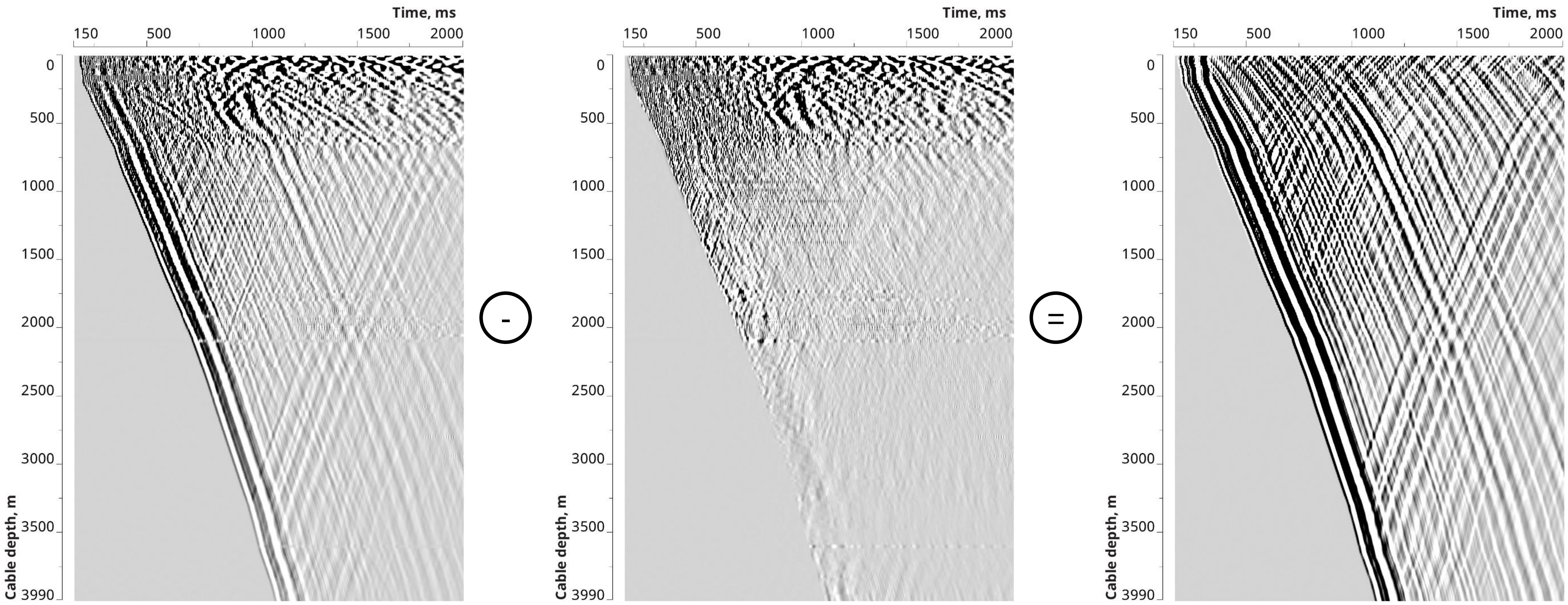
3. Wavefields analysis

The key processing procedure is wavefield analysis. The purpose is to extract noises and individual useful regular waves from interference. The method is iterative subtraction with step by step refining of extracted components of wavefield.

Selection of regular events on every step is provided by combined FK, Polycor and median filtration along predetermined hodograph. Regular events for automatic extraction can be dp, dpds, dpup, dpus, dpupdp, dpupds, ds. Hodographs for these one fold dp, ds, dpup, dpus and multiples dpupdp, dpupds are generated from model. Other regular events can be correlated semiautomatically.

Iterative selection is repeated for each new signature after deconvolution.

3. Wavefields analysis



Raw wavefield

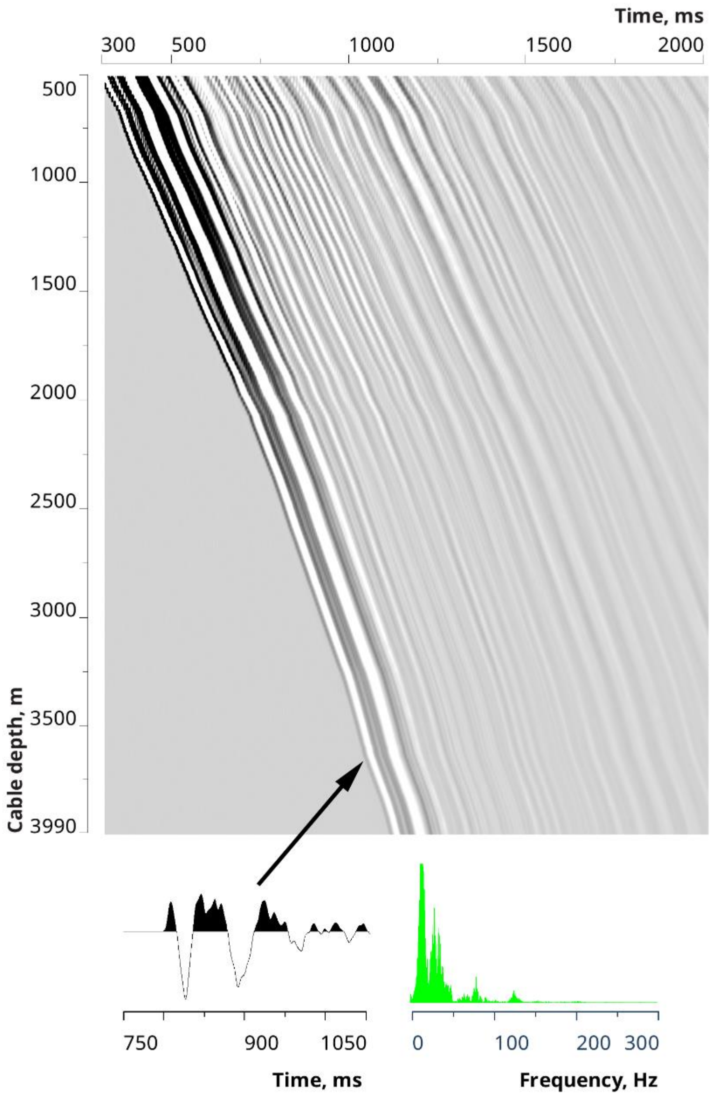
Noises

Useful P-waves

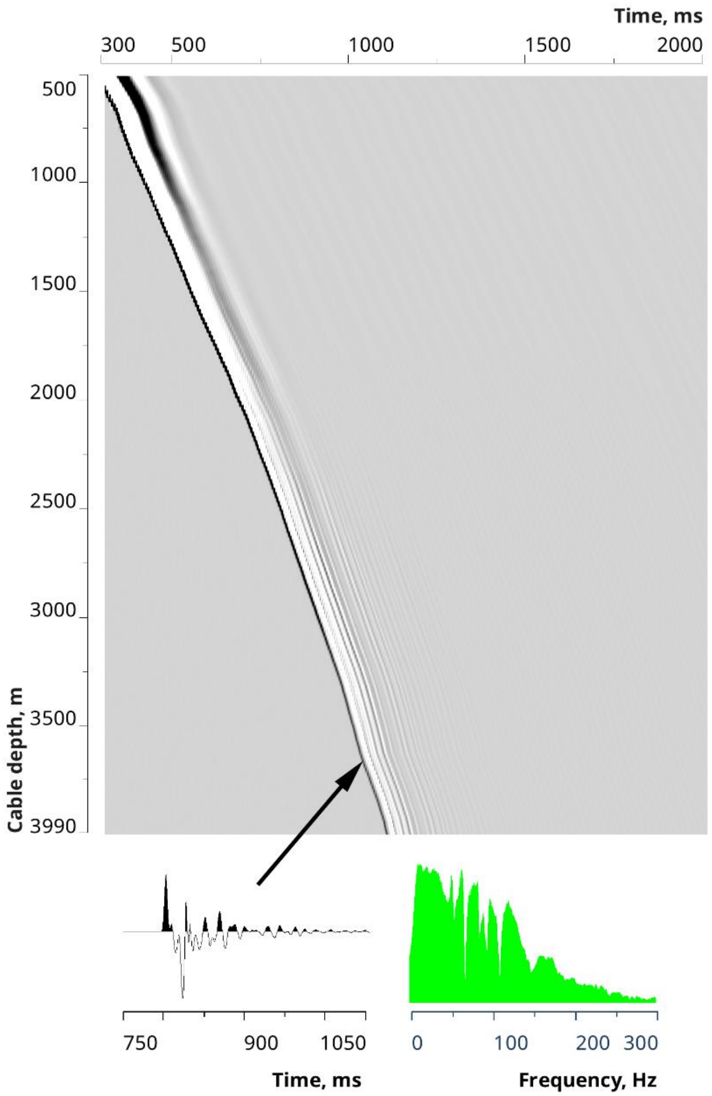
4. Prediction deconvolution

Prediction error operator is calculated from averaged downgoing waves to escape deformations of reflections.

4. Prediction deconvolution. Direct pressure wave, P-component



Before



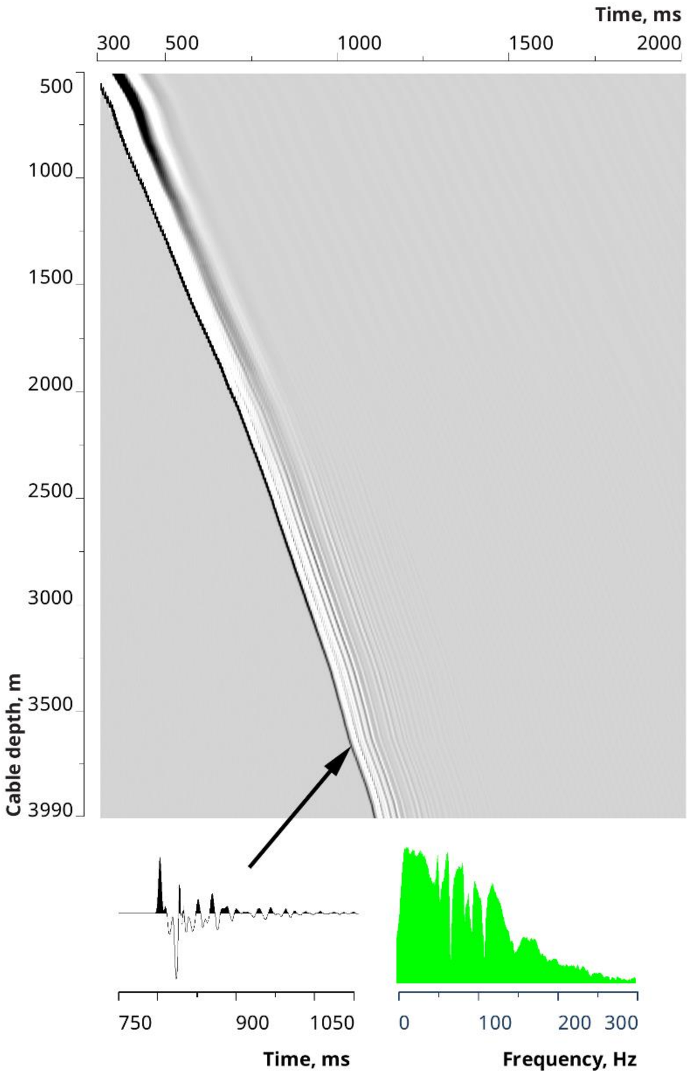
After

5. Spike deconvolution by downgoing signature

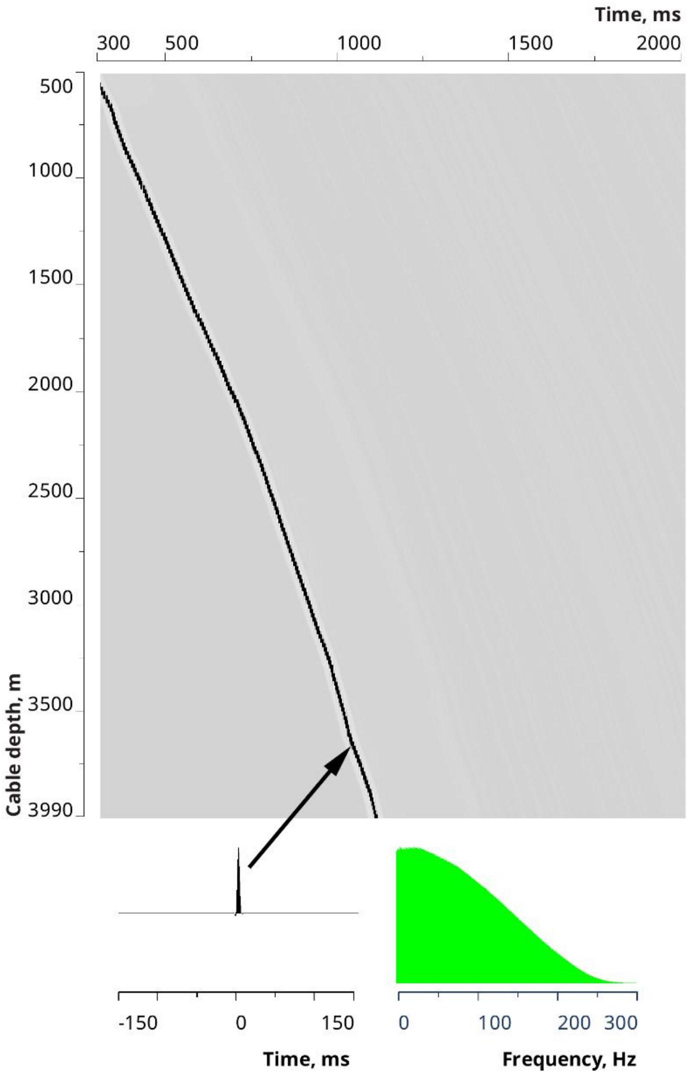
Spike deconvolution for near shot point is usually calculated from the direct wave at each depth after prediction deconvolution (PD) and applied to all wavefield components after PD. For distant shot points, either one averaged direct wave operator is used, or a complex one - before the head wave trace-by-trace, then one operator. The desired output is one unit per time of the model hodograph for a given shot point with a 0/300 Hz filter (with a sampling interval of 1 ms).

Spike deconvolution provides zero phase result.

5. Spike deconvolution (direct waves), P-component

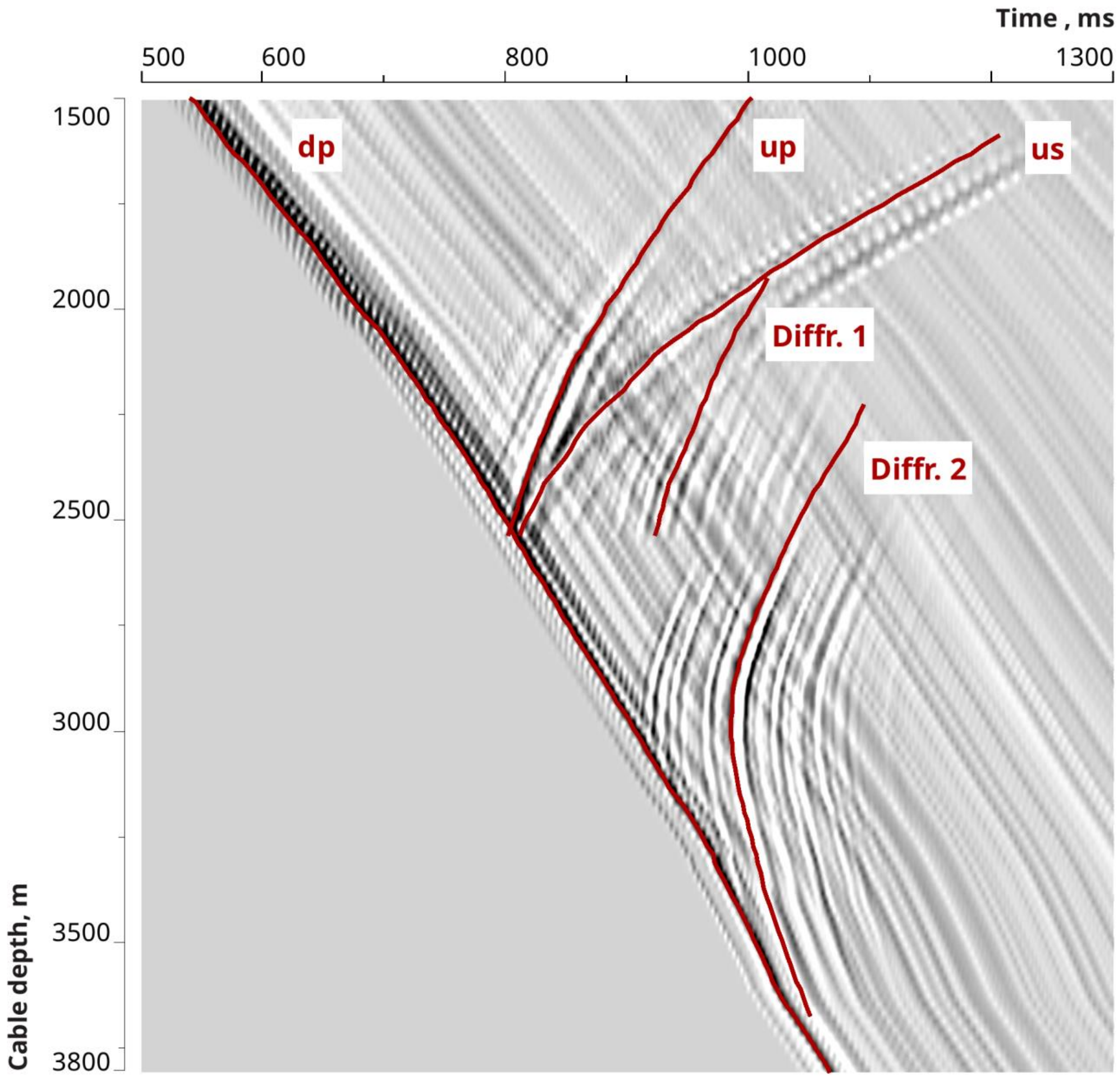


Before



After

5. Diffracted waves (R-component)

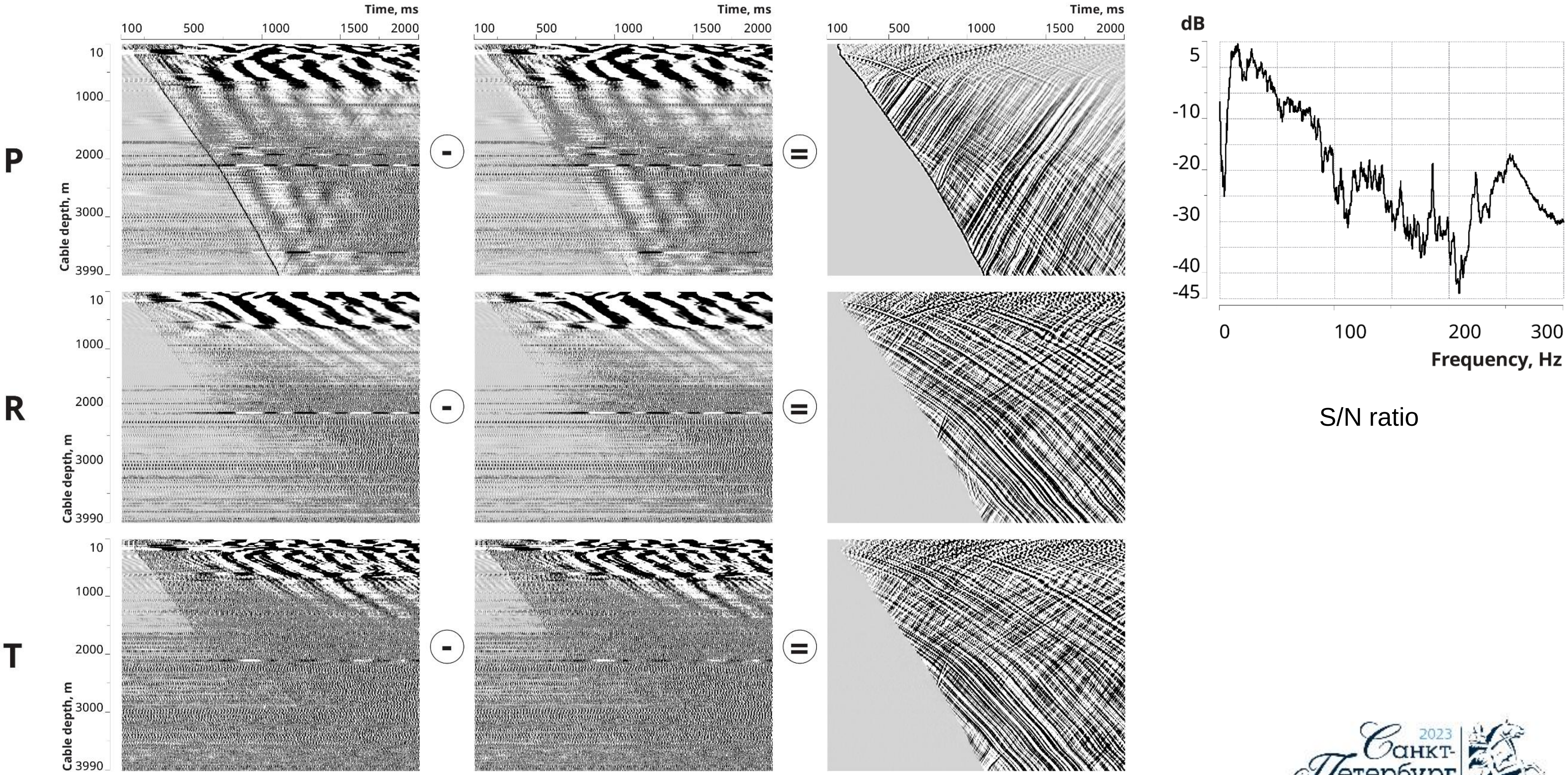


dp – downgoing pressure wave

up, us – reflected pressure and shear waves generated by steeply dipping boundary

Diffr. 1, 2 – diffracted waves

5. Fragments of deconvolved wavefield in wide spectrum 0-300 Hz



S/N ratio

Raw deconvolved

Detected noises

Useful waves

6. Tying up of VSP, LOG and Surface Seismic data

Initial data for tying up are:

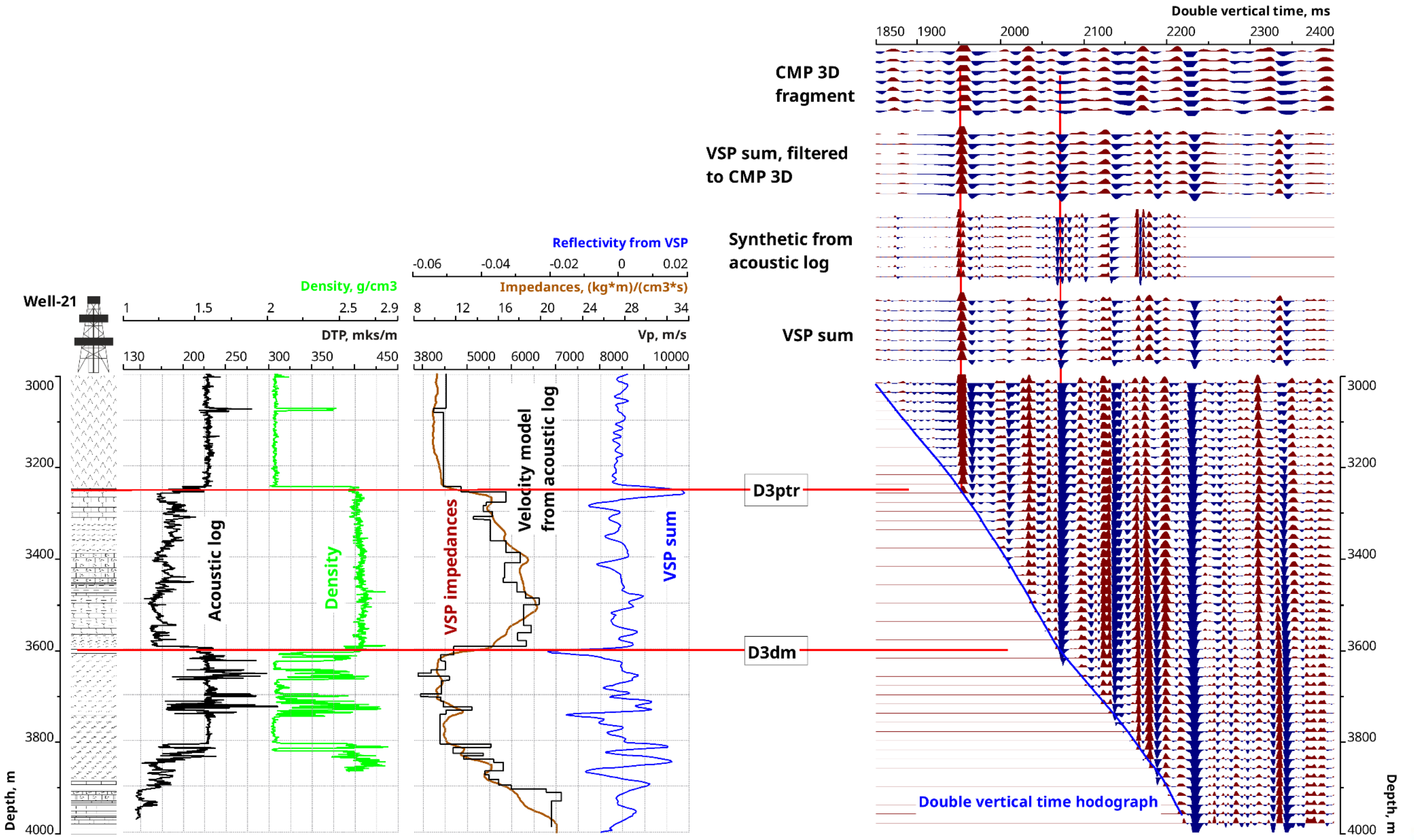
- Logs, preferably acoustic impedances, integrated to thin layers.

- Inversion of VSP corridor stack in wide spectrum (0–300 Hz for dt=1 ms). Near zero frequencies have to be added from model.

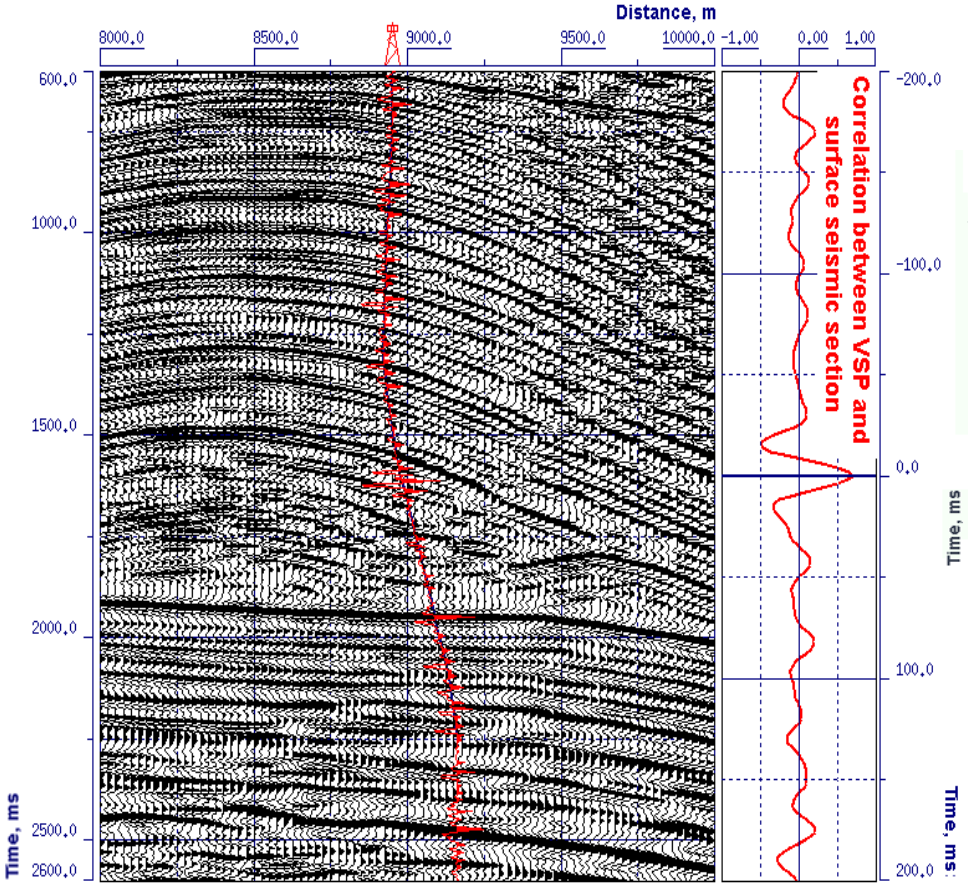
- CDP fragment.

Logs and inversion of VSP may be compared visually and digitally by correlation filtration of logs to frequency band.

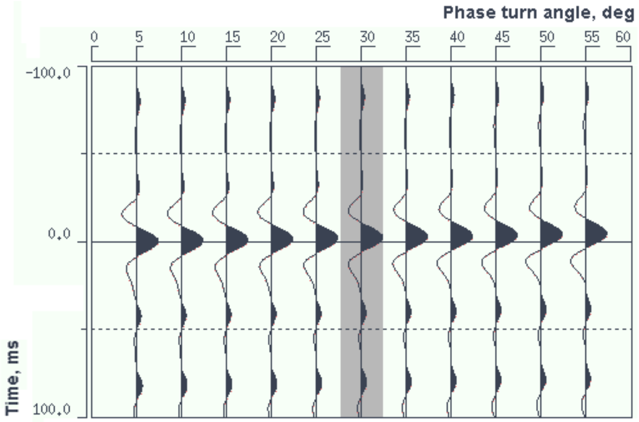
6. Tying up of VSP data with LOG and Surface Seismic data



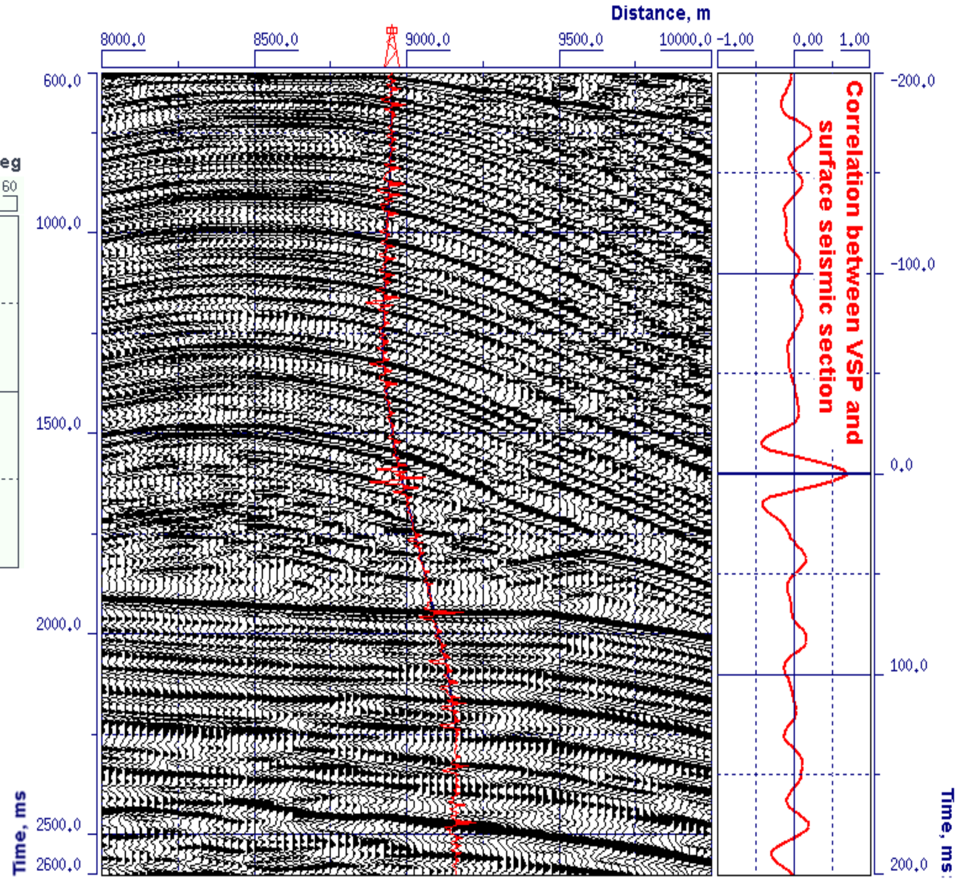
6. Tying up of VSP Corridor Stack (CS) with 3D data and phase rotation by CS



Tying up of 3D to VSP CS before rotation



Cross correlation controlled rotation of 3D data



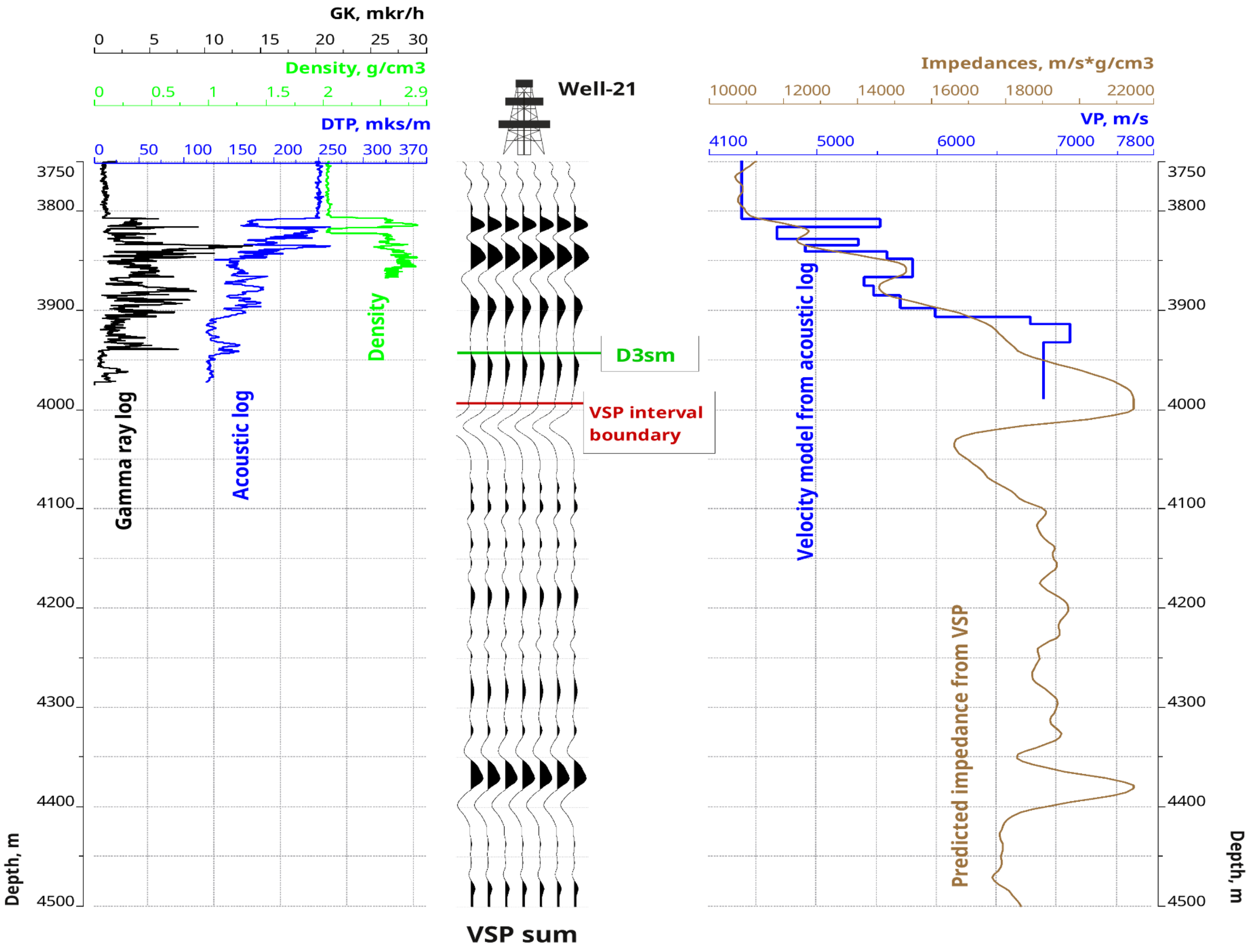
Tying up of 3D to VSP CS after 30^0. rotation

7. Prediction of acoustic impedances beneath a bottom of hole

Correlated reflections in the lower part of VSP make it possible to predict acoustic impedances below a bottom of hole through inversion of reflections. Velocities for prediction in depth scale can be assigned after correlation of marker reflections from neighboring wells, or calculated in proportion to acoustic impedances. Lithologic interpretation is based on impedance over a priori bonds for each region.

The next picture shows an example of acoustic impedances prediction from above bottom of hole to make sure the prediction in the opened-up interval matches.

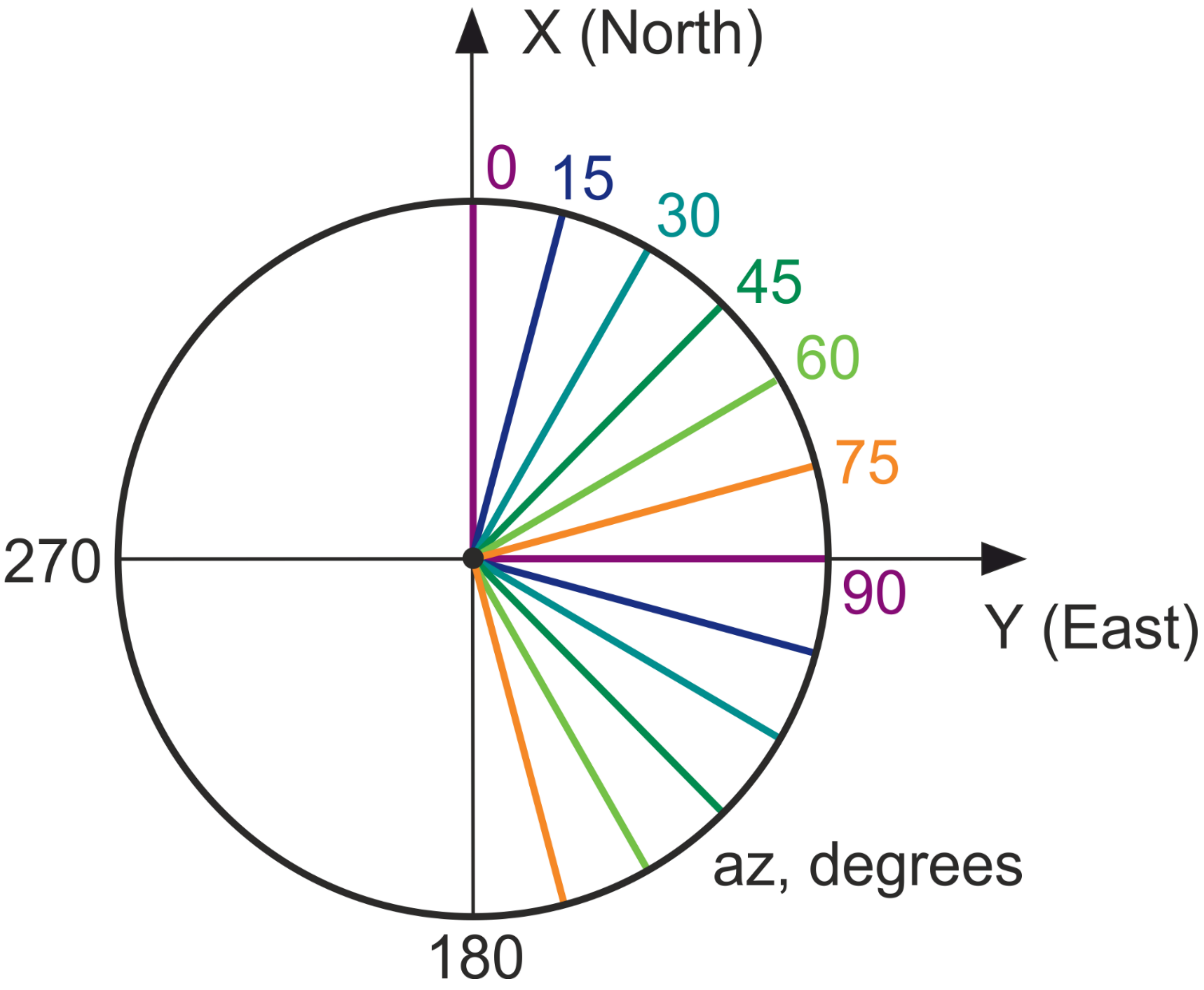
7. Prerdiction of section beneath a bottom of well.



8. Additional prospects of HDS technology

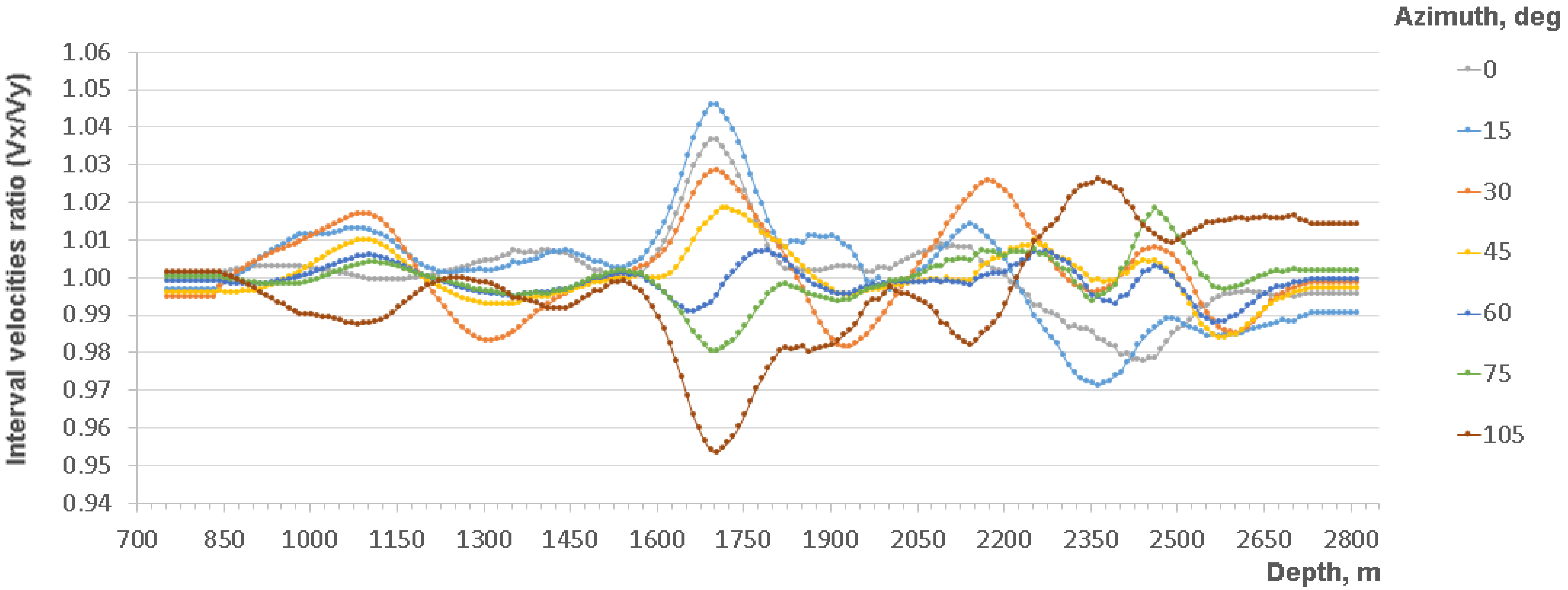
High S/N ratio in wide frequency band and subperfect wave separation make it possible to estimate dips and azimuths of layers, crossing the well and azimuthal anisotropy of shear waves. So the volume model of near borehole space becomes available as well as directions of vertical fractures, which can determine direction of hydro fracturing.

8.1 Estimation of shear waves anisotropy



Anisotropy: $$A(az) = \frac{Vx(az)}{Vy(az)}$$

8.1 Estimation of shear waves anisotropy

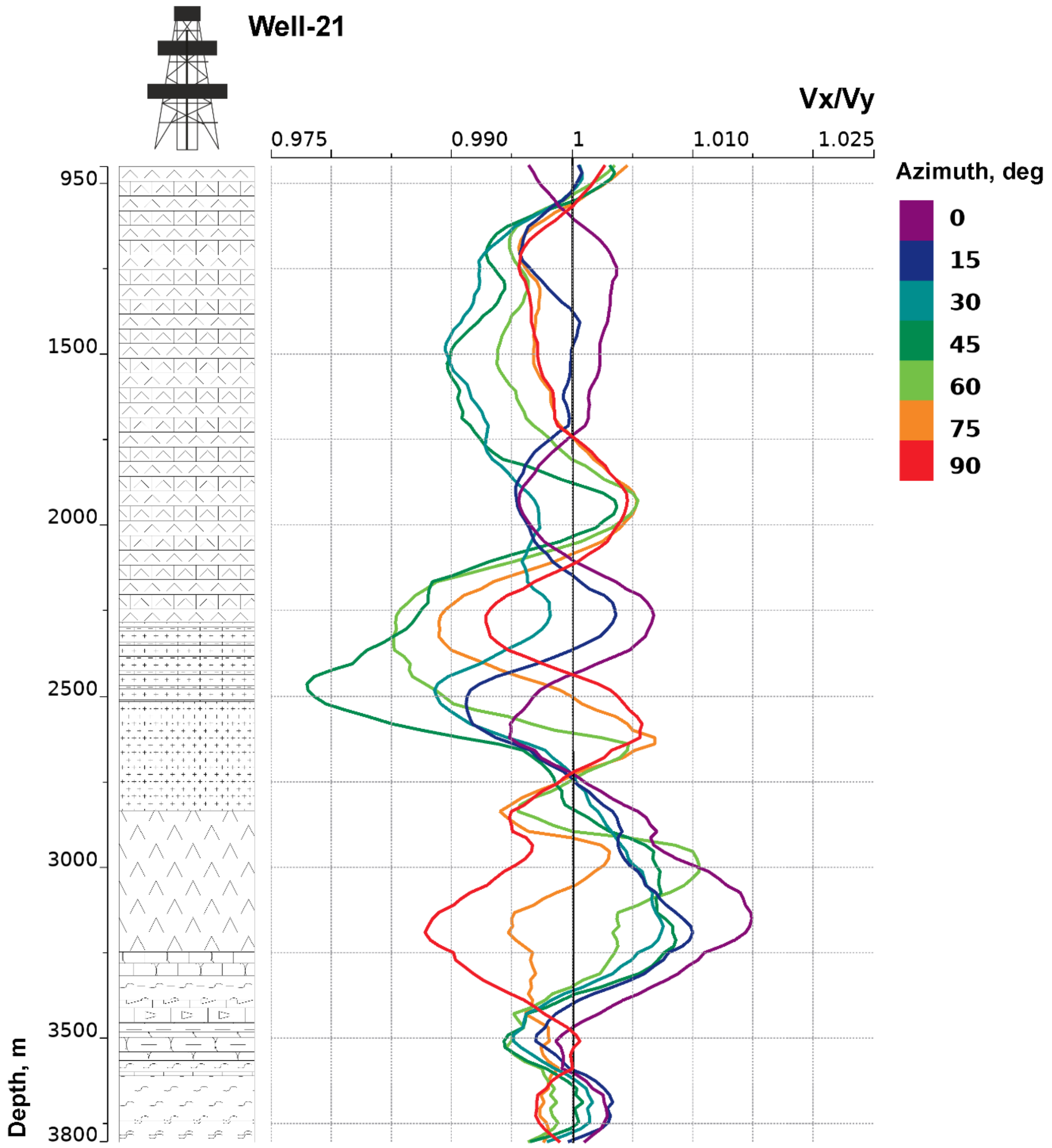


Cross relations between azimuthal curves show, that there is velocity anisotropy approximately 4.5% along azimuth 15^0 in depth interval 1650 – 1750 m. This anomaly can be evidence of strong fracturing along this direction.

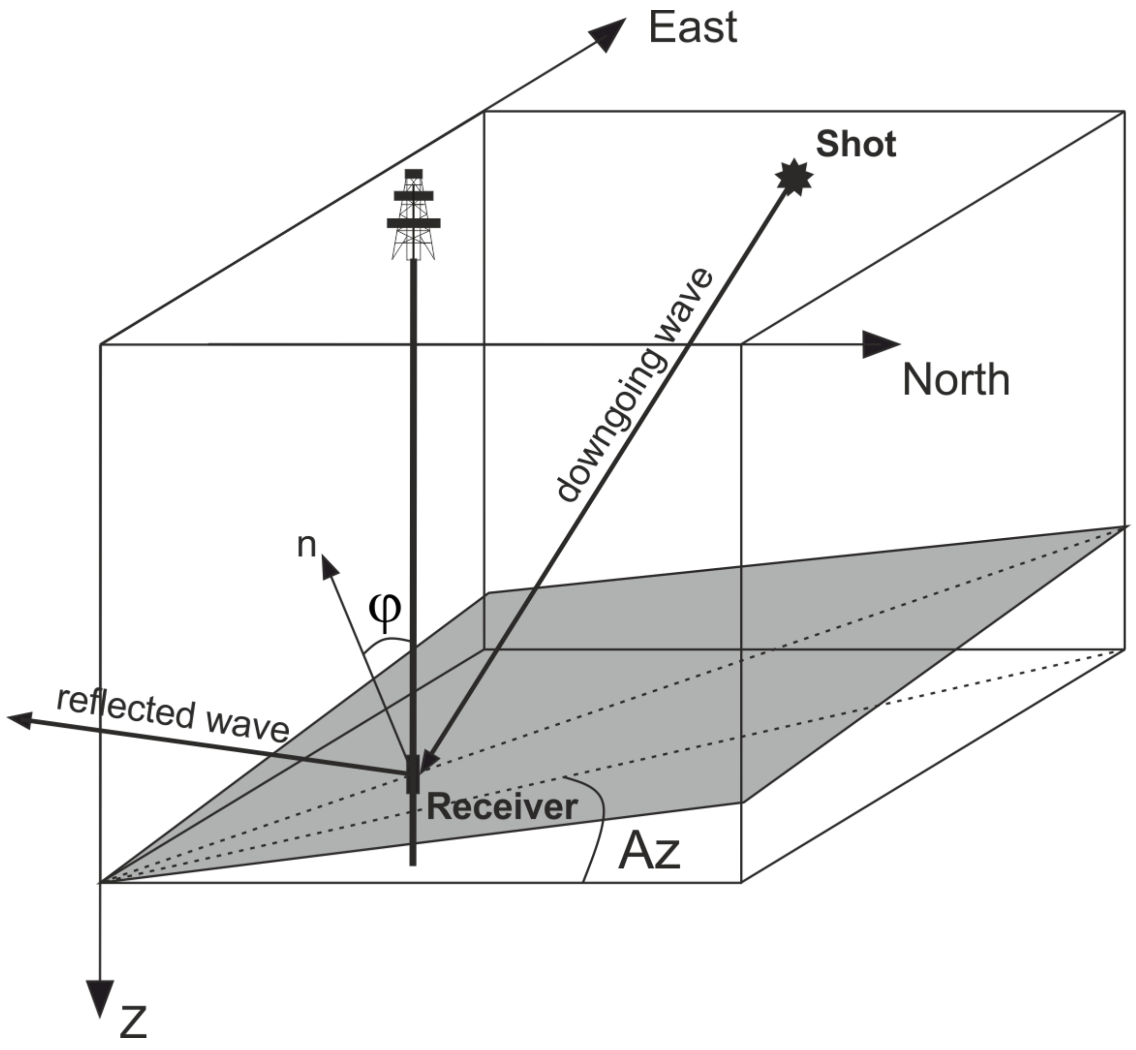
8.1 Estimation of shear waves velocity anisotropy

Legend

- Terrigenous rocks
- Interbedded limestones, clays
- Stone salts
- Anhydrites with interbeds of carbonates
- Clays, limestones, dolomites
- Limestones, dolomites
- Clay limestones
- Marl
- Dolomitic limestones
- Clay sandstones
- Sulfate-carbonate rocks
- Stone salts, clays, marls
- Rock salts with clays, carbonates

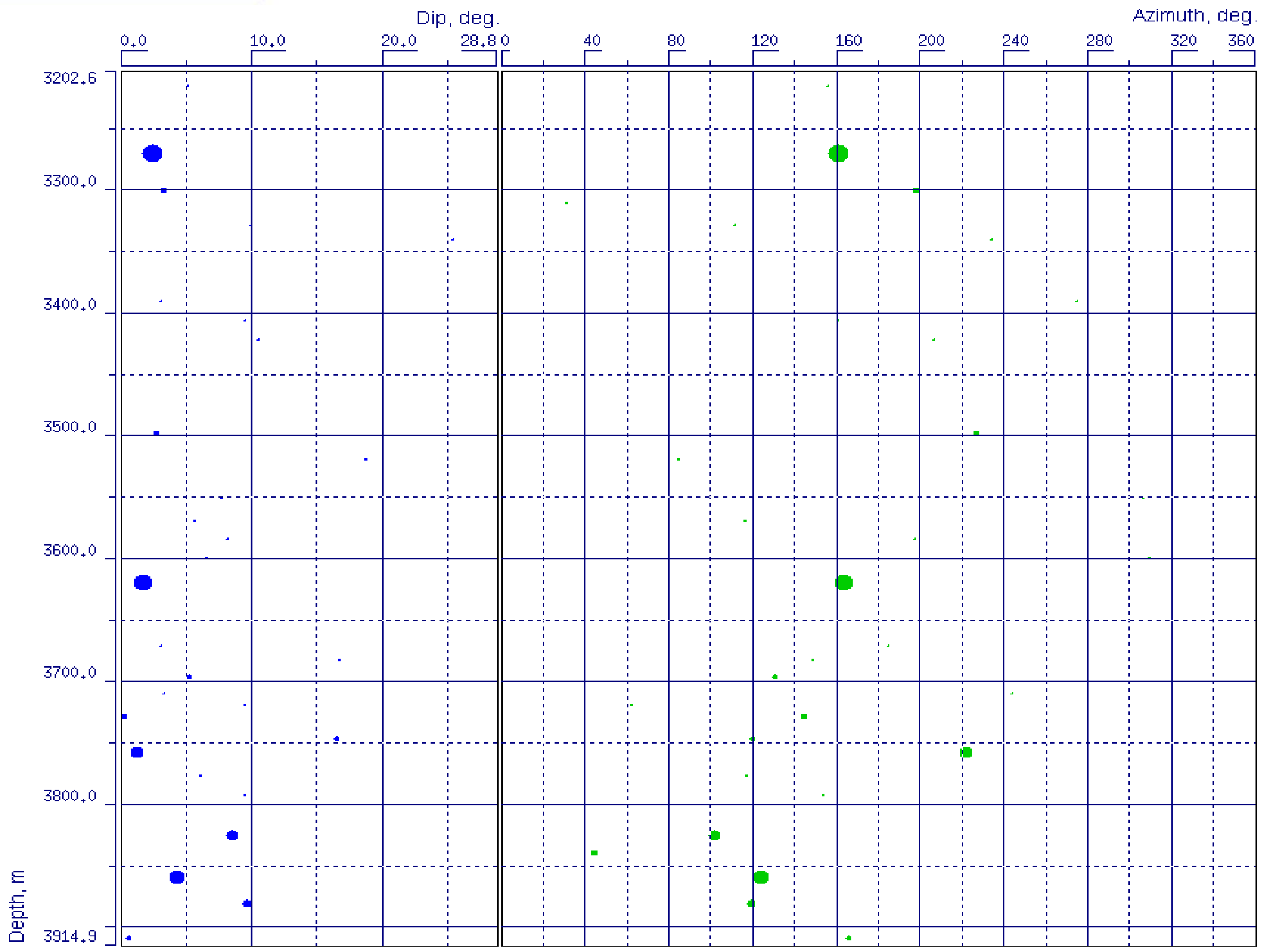


8.2 Determination of layers dipping (dipmetering)



φ - slope of border
Az – azimuth of slope

8.2 Estimation of boundary dip (dipmetering)



Dips and azimuths of boundaries estimation. Size of point depicts reliability of determination procedure.

Estimates of slopes

Depth,m	Dip, deg.	Azimuth, deg.
3270	2.4	160.8
3619	1.7	163.4
3758	1.1	221.8
3825	8.6	101.9
3858	4.2	123.7
3881	9.6	119.7

Геомодель

9. Automatic HDS processing using Artificial Intelligence (AI). Intellectual Robot (IR)

Intelligent correction of arrival times and signatures by reference geophones. Key decision steps:

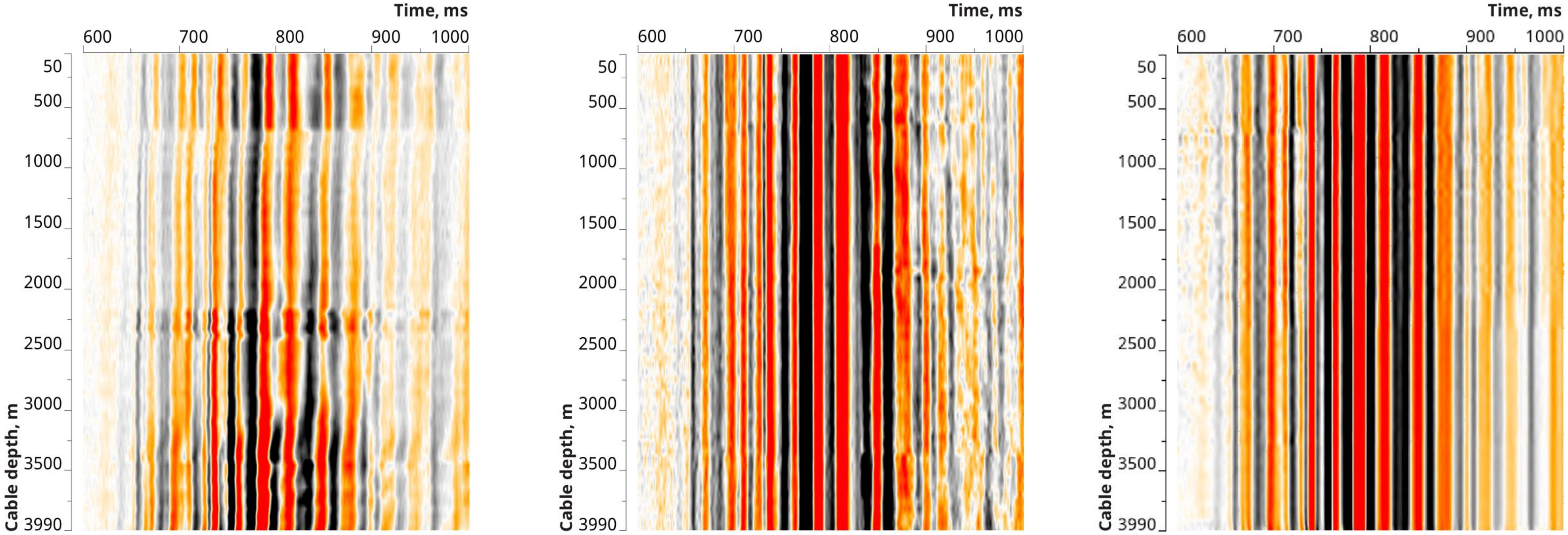
1. Preliminary first breaks hodograph construction for VSP depth sonde. It is based on intelligent analysis of wave field characteristics to estimate intervals with stable extraction of direct wave arrivals and subsequent picking of times of first breaks at these intervals. At intervals with unstable correlation, the hodograph is constructed on the basis of modeling using a generalized velocity model for current study area.

2. Determination of static corrections for each reference geophone. Selection of the best reference geophone based on the analysis of the application of calculated static corrections to the first breaks times from VSP depth sonde.

3. Analysis of the best reference geophone traces and selection of a calibration trace for signature correction operators construction. Both reference geophone and VSP depth sonde signature correction.

9. Correction of times and signatures by reference geophone. Comparison of manual and automatic processing with IR

Reference geophone



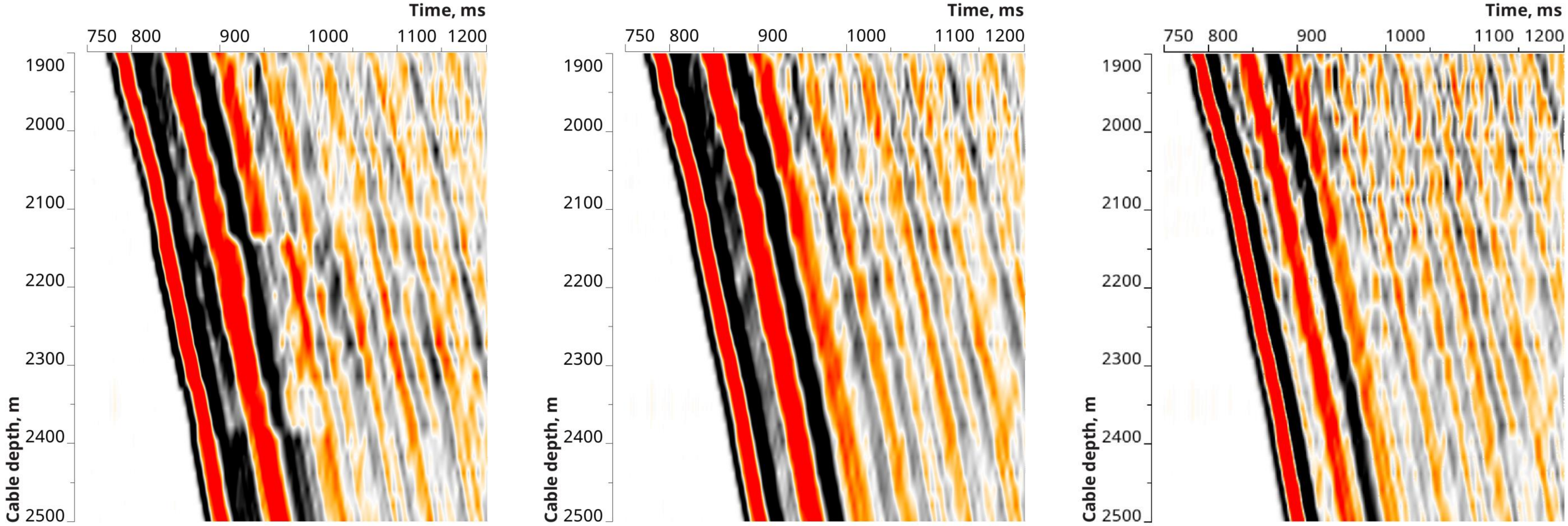
Before correction

Manual processing

Automatic processing with IR

9. Correction of times and signatures by reference geophone. Comparison of manual and automatic processing with IR

Vertical component of VSP sonde (fragment)



Before correction

Manual processing

Automatic processing with IR

Conclusions

1. HDS processing of real VSP data provides highest resolution in frequency band 0-300 Hz. Approximately seven octaves (2-300 Hz) provides multicascade deconvolution and 0-2 Hz provides averaged model.

2. Accuracy of time to depth correspondence reaches 1-2 m. It becomes possible to expand spectrum of reflections on surface.

3. Tying up of Surface Seismic data and LOG data through VSP by HDS technology is much more reliable than modelling by LOGs, because last approach have some uncertainty in choice of signature for convolution.

4. HDS technology makes it possible to determine directions of fracturing by exchange shear waves from single shot point, provides more accurate prediction of section beneath the bottom of hole and determination of space position of reflections (dipmetering).

5. Automatic processing by Intellectual Robot is more efficient than interactive one.

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