Since its invention in the 1950s VSP, or vertical seismic profiles method (Gal'perin, 1974) has been widely used by geophysicists for detailed studies of hydrocarbon reservoirs. VSP naturally allows for

- registration of full vector multi-wave response of the medium,
- source impulse shape estimation and zero-phase deconvolution,
- direct determination of layer velocities by means of kinemaitc inversion,
- anisotropy detection,
- dynamic inversion and
- high resolution imaging with the use of both P and converted S waves.

However, all these advantages will be available only if proper processing techniques are applied. In this paper we will focus on some general principles on which key stages of VSP data processing should be based.

It is the wave field separation procedure that mainly affects the quality of VSP data processing results. This procedure must primarily preserve dynamic features of target waves. This can be met by following some common principles which are given below.

1. **Keep additivity**

The core meaning of the *additivity* principle is that actual *separation* of a vector wave field is carried out, not just extraction of specific waves. After each wave field transformation (i.e. noise reduction, wave subtraction) both the result of the procedure and the residual should be saved. The residual can always be derived by subtracting the output from the input. Thus, as wave field separation is finished, one will have a set of various components of the raw seismic section: target wave fields of different types, artefacts and unwanted waves (such as tube waves and casing vibrations), incoherent noises (for example, harmonic and spike noise) as well as the residual wave field obtained after subtraction of all referenced components. Having all these results, one is free to restore the original wave field or refine any of the components at further stages of processing by additional filtering or adjustment of wave parameters (travel time and polarization) and keeping in mind that undesirable energy must be always transferred to noise and residual wave fields.
Fig. 1 shows an example of the proposed wave field decomposition technique. Fields of irregular noise (harmonic noise, etc.), downgoing and upgoing P waves, downgoing and upgoing converted PS waves, tube waves and residual field are presented.

2. **Use reference velocity model**

The principle of the *model-based processing* is yielded from the following aspects. According to conventional VSP processing workflow, when approaching to the wave field separation stage, velocity model of the medium should already be derived as a result of kinematic inversion of all available arrival times (which may include not only direct wave hodographs recorded for different shot point offsets, but also clearly correlated hodographs of waves of other types (Stepchenkov et al., 2005)). This velocity model can be implemented during initial wave field separation. Based on the known velocity model, vector wave field may be (1) transformed to a wave directed ("tracking") component where the most of target wave energy resides (Ferentsi et al., 2003); (2) flattened (via NMO correction procedure) which makes the subtraction of target waves easier as their initial hodograph may be defined just as a vertical line in the time-depth domain. Such techniques become extremely important when trying to discriminate waves with similar apparent velocities and polarization parameters (for instance, upgoing converted PS waves and upgoing PSS waves; PSS denotes monotype SS reflection generated by downgoing converted PS wave).

3. **Iterate to reach more accurate results**

The *iteration* principle is implemented in the wave field separation procedure as sequential subtraction of different types of waves in order of their decreasing energy and further adjustment of their parameters when other waves are absent and thus interference is reduced.

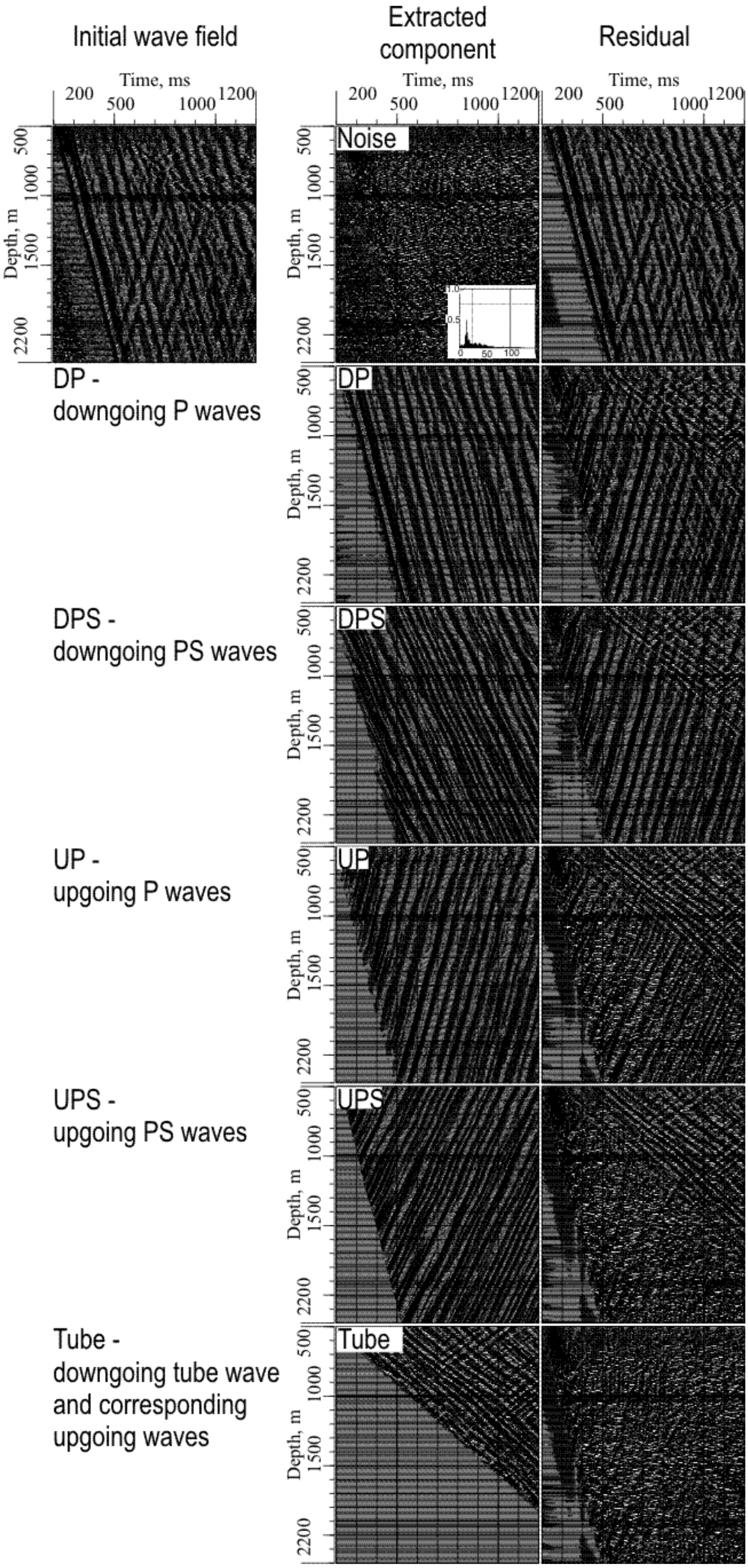

Fig. 1. Additive wave field decomposition

At first iteration of target wave selection large spatial aperture for estimation of average impulse shape must be defined for better discrimination from other waves. After the first iteration selected wave fields almost do not contain waves of inappropriate types. On the other hand, true parameters of target waves are distorted (averaged along depth axis), and a part of their energy is left in the residual field. Then each extracted wave field should be added to the residuals and after adjustment of wave and velocity model parameters subtracted again on the narrower spatial base. Such a process is repeated while any coherent events can be indicated in the residual wave field.

Zero-phase deconvolution based on the direct wave impulse is the next stage of processing. The ultimate principle here is the maximum expansion of available frequency band accounting for a given signal/noise ratio. Fig. 2 displays an example of downgoing and upgoing wave field deconvolution. Amplitude spectrum of upgoing waves after deconvolution ranges from 8 to 150 Hz.

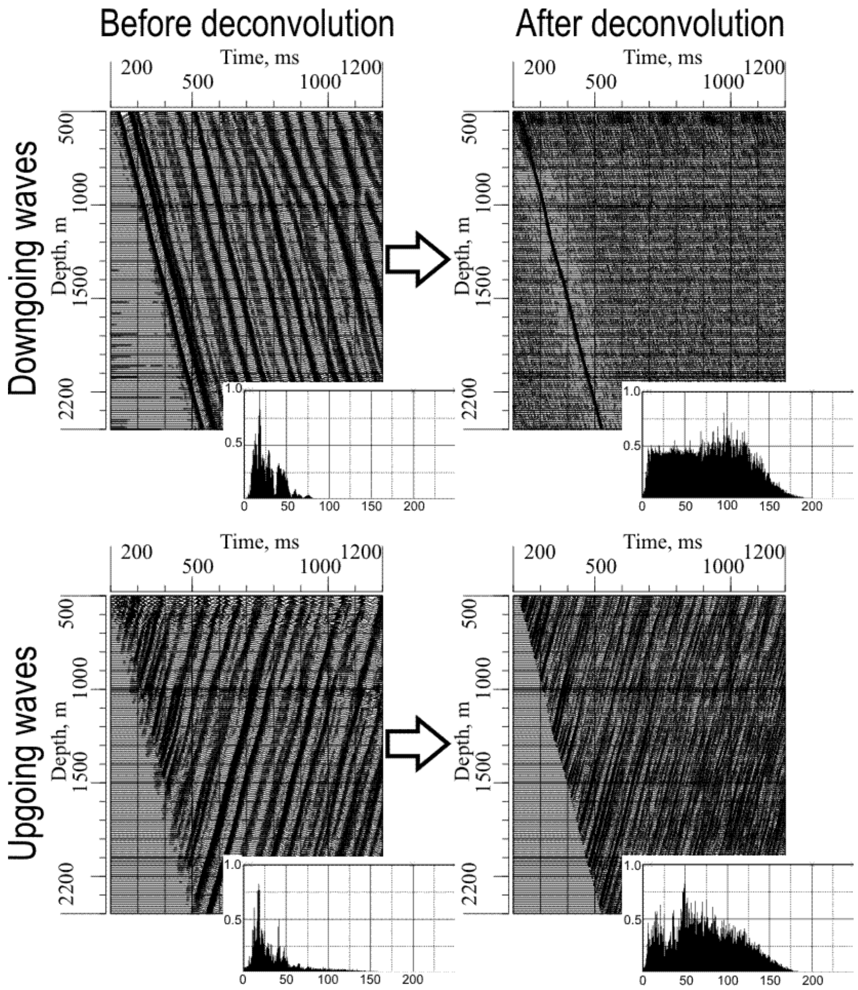

Fig. 2. Zero-phase deconvolution of VSP data

At the final stage of processing of zero- and near-offset VSPs dynamic inversion is usually carried out. When dealing with only P waves, optimal inversion for acoustic impedance recovery can be applied (Tal-Virsky, Tabakov, 1983). In the case when intensive converted shear waves are observed, vector inversion algorithm should be implemented (Yakovlev et al., 2005). For far-offset VSPs migration procedures are performed to construct seismic image of the near-borehole area.

Application of the established principles provides for high quality results of VSP data processing. Fig. 3 presents the acoustic impedance recovered from VSP data in comparison with log data (Rhob). Such a perfect match as can be observed on the given figure confirms the accuracy of the velocity model estimated by VSP and hence ensures the reliability of the tie between surface seismic data and lithological section in the borehole.

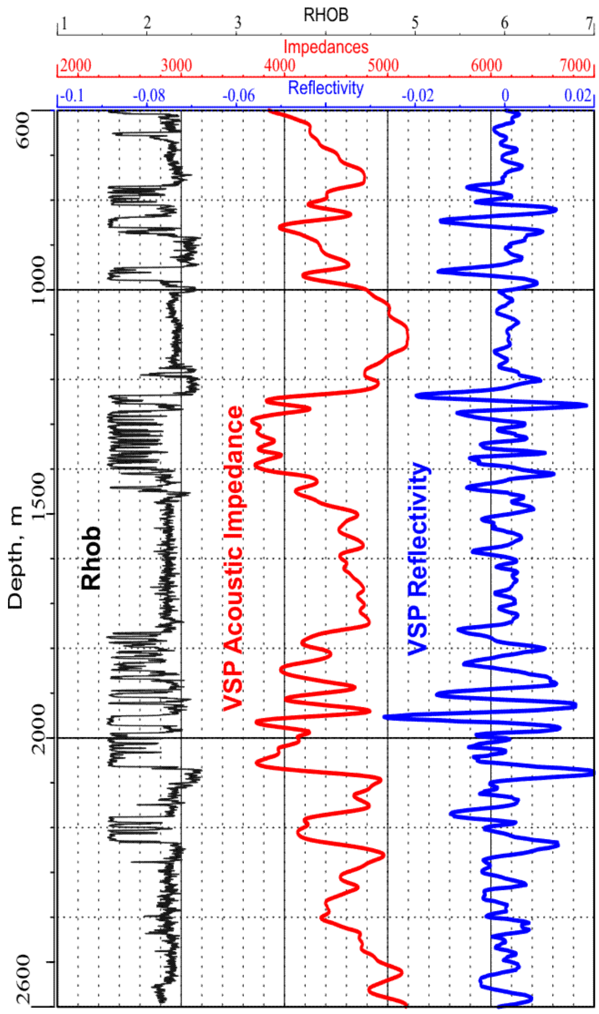

Fig. 3. VSP-log tie

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