Using of the High-Frequency VSP data for near-well area studing (on the examples of Western Siberia fields)

E. Bezmaternykh, E. Vinogradov, V. Bezmaternykh, NIIMorgeofysika Service Group, Murmansk, Russia
E. Blias, V. Khatchatrian, L. Shavina, Revolution Geoservices Inc., Calgary, Canada

2005 CSEG National Convention

Summary
The VSP method is based on the borehole seismic registration, reflected waves extraction and imaging near-well medium (Galperin, 1971, Hardage et al., 1983). VSP data gives an opportunity to obtain detailed information about the productive layer's structure and to investigate the lateral changes of their properties in the vicinity of the well. To achieve this, it is necessary to use precise acquisitions and quite sophisticated software for VSP processing and interpretation, including the most important problems: wavefield separation, velocity model reconstruction (including anisotropy) and imaging. Special acquisition and processing technique has been developed and applied in different regions of Western Siberia. It provides the means of improving our knowledge of the reservoir properties through the high seismic resolution of VSP data.

Introduction
High-frequency VSP technology has been developed in NIIMorgeofysika - Service Group during last seven years. It includes well acquisition (six 3-component receiver bore tool), air guns, processing and interpretation software. Here we consider application of this technology in Western Siberia. The main targets of the borehole seismic survey were two gas-saturated layers in the Western Siberia gas-field. The layers depth interval – 1180-1310 m, the upper layer has thickness 33 m, the lower one – 35 m. The reservoirs are the Cretaceous sandstones, characterized by the structure and properties changing all over the gas-field area. In the last years a gas production is carried out with sub-horizontal production wells, having a length of a well bore horizontal part 250-300 m. The high quality VSP data allows us to obtain accurate high-frequency images, as well as reliable estimation of the gas layer properties.

Acquisition
For VSP observations, NIIMorgeofysika - Service Group uses its own original equipment - digital borehole tool, which has been developed and designed during the last three years. The down-hole sonde contains 6 record 3-component units, real time digital data transmission and surface data acquisition system. Small size and weight of receiving modules make it very convenient to run VSP survey. In combination with a significant sidewall force (more than 200n) and a low level of input noise, this complex provides high registration accuracy in a wide frequency band.

At last time an air gun has been used as a source of seismic signals, patent RUN 2240581, 20.11.2004. It works in shallow wells and other volumes, which are filled up with water. The advantages of the air gun, in comparison with existing ones, are based on reliable abrasive action protection during air gun functioning in sand and mud, a large volume of a compressed air and a high velocity of its blowout. It enlarges intensity and frequency content of the generated wavelet. X and Z-components of the shot 1 and 2 are shown on Fig. 1, 2a, and 2b.

Main problems and processing steps
The VSP data processing and interpretation technology has been described in Blias and Chavina, 1999. We distinguish four main steps in our processing flow.

1. The preliminary zero-offset VSP processing and analysis included: stacking, editing, first breaks picking and source frequency-dependent corrections. To calculate and apply these corrections three surface geophones has been used. This was followed by amplitude recovering (geometrical spreading), wavefield separation, VSP inverse filtering and corridor stack. After VSP inverse filter calculation and application on upgoing wavefield, we use this upgoing wavefield and log data (sonic log, density and gamma ray) to tie reflection to lithological and stratigraphic boundaries, Fig. 3 (tying reflections).

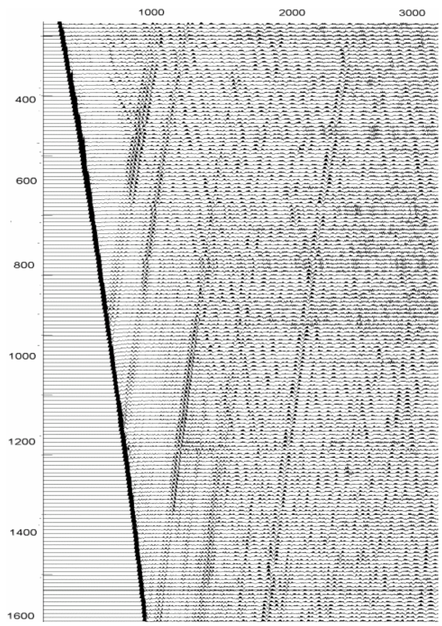

Fig. 1. Offset 1. Z-Component

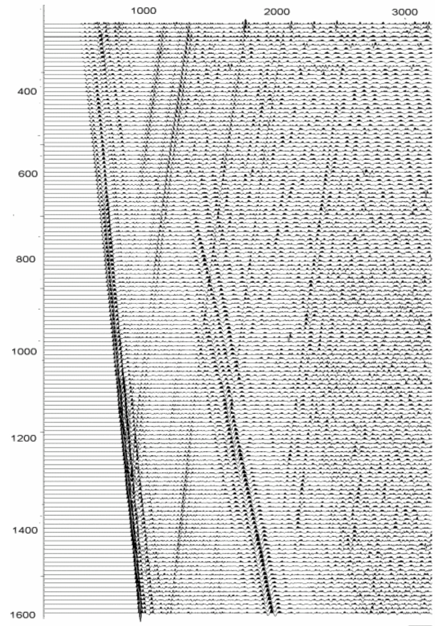

Fig. 2a. Offset 2. Z-Component

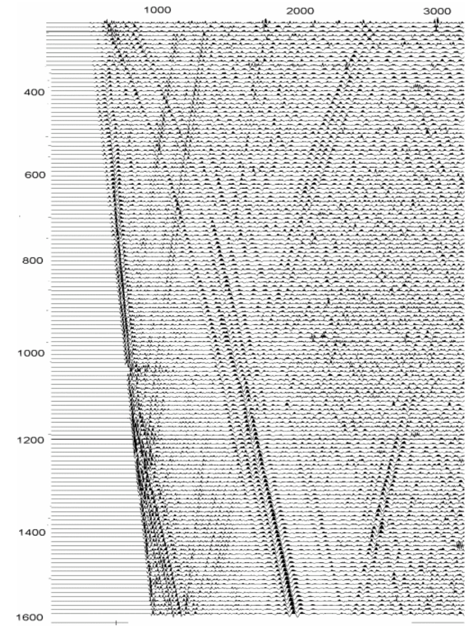

Fig. 2b. Offset 2. X-Component

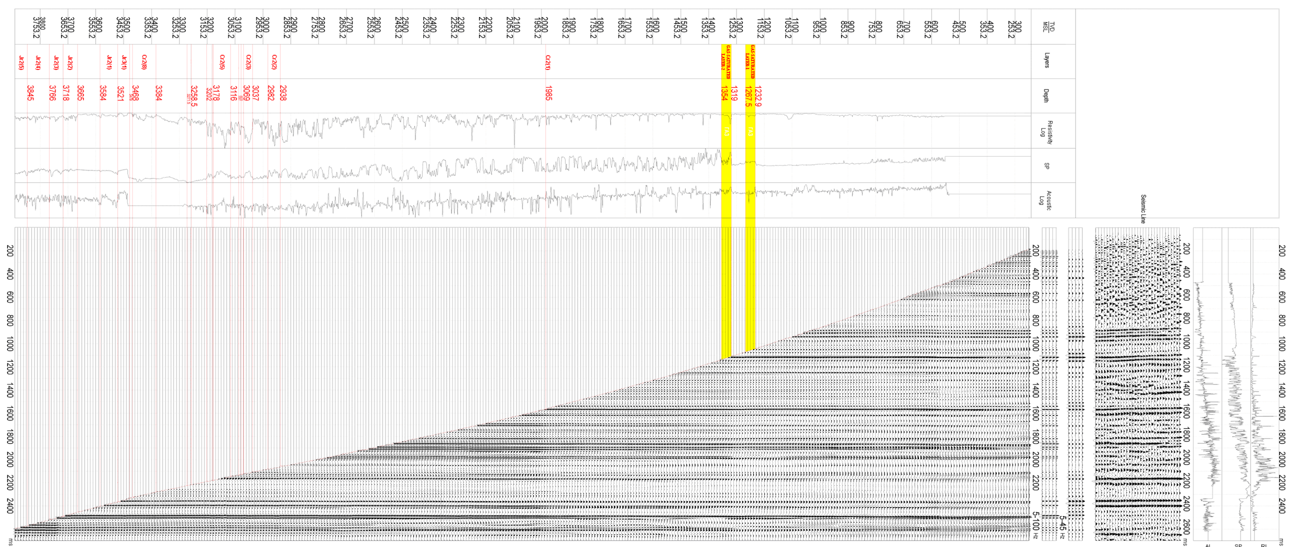

Fig. 3. Log data, upgoing VSP wavefield and seismic section

The raw offset VSP data were stacked, edited and improved for the source frequency-dependent corrections. Then first breaks have been picked and downgoing and upgoing waves have been described for the applied wavefield separation. Traveltime inversion (depth layer velocity model with anisotropy layers) of traveltime data was performed to reconstruct an image into different directions.

2. Offset wavefield separation. This is one of the most important procedures in VSP data processing. A special optimization approach has been developed (Blias and Katkov, 1987c) and extended for offset VSP wavefields (Blias, 2005). Fig. 4 shows results of wavefield separation for the offset 3.

3. Traveltime inversion and depth velocity anisotropic model determination using downgoing and upgoing picked traveltimes. This approach is different from linear tomography method (Salo and Schuster, 1989) and it allows us to improve interval velocities and boundaries. Now it is commonly accepted that most rocks are anisotropic to some extent. For the accurate VSP imaging, we have to take into account anisotropy of seismic velocities. We use optimization approach (Blias, 1987a) to determine depth layered velocity model with anisotropic layers. In each layer, we describe velocity with the function suggested in (Blias, 1987b)

$$v(\theta) = k\, v(0)/[\sin^2\theta + k^2 \cos^2\theta]^{1/2} + b\, v(0) \sin^4\theta \qquad (1)$$

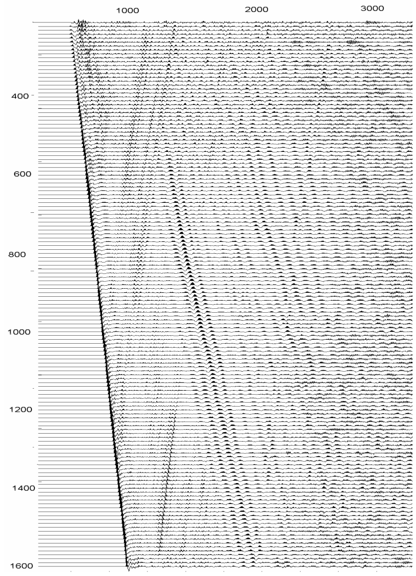

Fig. 4a. Z-Component

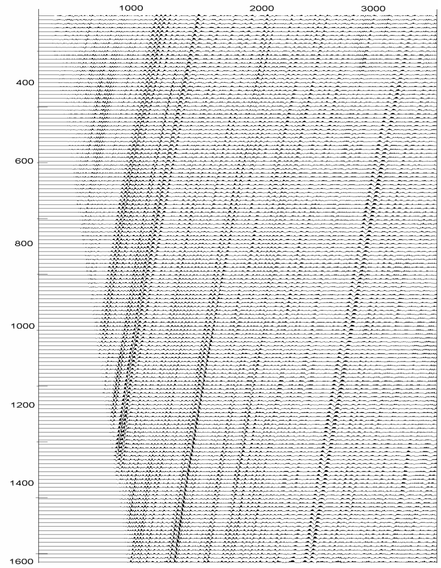

Fig. 4b. Upgoing PP wave

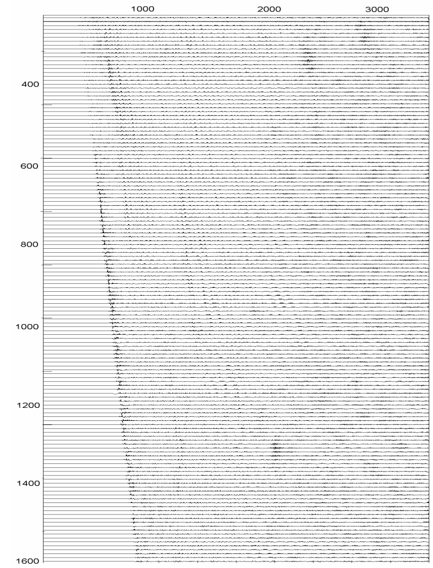

Fig. 4c. Residual Z-component

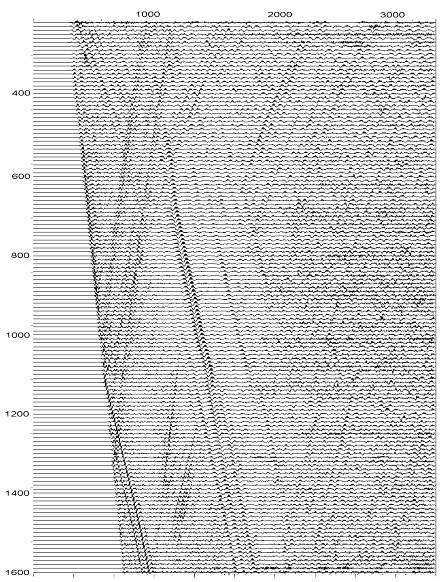

Fig. 4d. X-Component

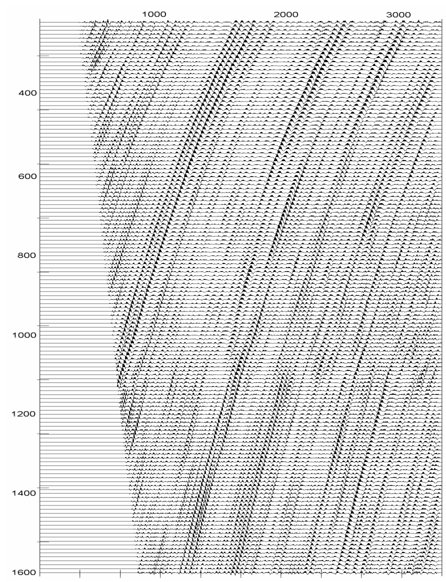

Fig. 4e. Upgoing PS wave

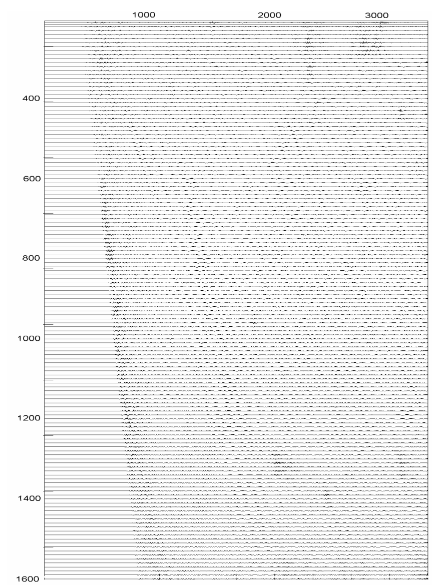

Fig. 4f. Residual X-component

First term in (1) is an ellipse, so the coefficient b describes an anelliptical term; θ is an angle between the ray and vertical axis. From (1) we can find connection between a, k and Thomsen parameters ε and δ (Thomsen, 1986):

$$k = 1/\sqrt{1-2\delta}\,, \qquad b = \varepsilon - \delta$$

$$k = 1/\sqrt{1-2\delta}\,, \qquad b = \varepsilon - \delta$$

4. VSP-CDP transformation. This is done through raytracing for the model, which is obtained in the previous step. For raytracing we use approach from (Blias, 1985), extended to anisotropic medium. For traveltime inversion with use the least-squares method, extended to anisotropic medium (Blias et al. 2003).

Some interpretation results

VSP-CDP section for two shot points are shown on the Fig. 5a, 5b.

The interpretation was carried out by comparison of the depth seismic sections traces with the closest to the well trace (offset – 25 m), where seismic record features are correlated with lithological column and log data, first of all with density (gamma-gamma) logging and with acoustic logging. The acoustic impedance high values and strong positive peaks of depth sections traces correspond to the compact and non-gas sandstones. The gas saturation of the porous and permeable sandstones decreases the impedance values. Therefore, qualitative reservoirs with high gas saturation correspond to negative peaks of a seismic record.

It was established that the horizontal borehole optimal drilling direction for the lower layer is azimuth 301˚, where from the offset about 220 m the thickness of the most high-saturated reservoir part begins to increase. The structure and properties of the lower layer are constant in all offset interval from the borehole (up to 370 m) along the azimuth 196˚.
It was recommended the horizontal borehole drilling for the upper layer also in the azimuth 301˚, as in an orthogonal direction (azimuth 196˚), from the offset 170 m, the changes are observed, which are connected with the reservoir claying and decreasing of its thickness

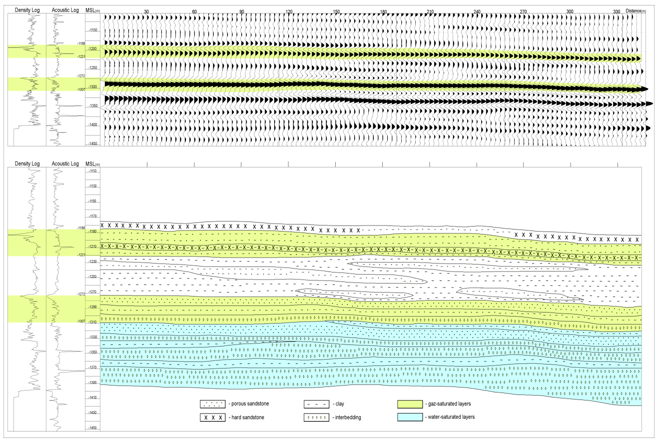

Fig. 5a. VSP-CDP section for shot 2 (azimuth 196°)

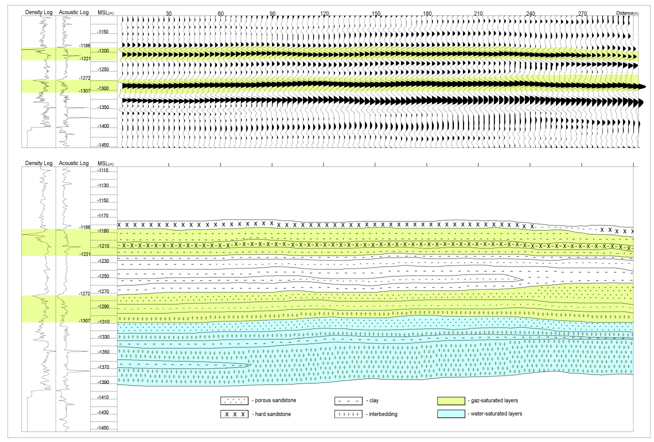

Fig. 5b. VSP-CDP section for shot 3 (azimuth 301°)

Conclusions

A complex high-frequency VSP technique has been developed. The VSP survey results depend on many factors: signal generation, signal registration condition in the borehole, specific processing and interpretation methods. NIIMorgeofysika Service is dealing with all these problems: VSP registration tool, air gun and software. Special methods have been developed for the VSP processing, including new wavefield separation, traveltime inversion and VSP-CDP transformation in the layer anisotropic medium. It allowed us to obtain high-resolution image and determine lateral changes in target layers up to 370 m from the well.

References
Blias E., 1985, Approximated method of ray calculation 3D layered media, *Soviet Geology and Geophysics*, 12, 69 – 77.
Blias E., 1987b, Traveltime in the media with gently dipping curvilinear boundaries and anisotropic layers. *Acad. News, Phys. of Earth*, N7, 67 – 75.
Blias E., Katkov U., 1987c, Optimization algorithms for selecting three components VSP seismograms. *Automatic System of Geological-Geophysical Data Acquisition, Holding and Processing*. Riga, 64-72.
Blias, E., 2005, VSP wavefield separation in time domain, EAGE 67th Conference & Exhibition — Madrid, Spain.
Blias E., Chavina L. 1999, High frequency VSP methodology and its application to the detailed investigation of near-well space. SEG International Exposition&69th Annual Meeting, Expanded abstracts, Houston.
Blias E., Khatchatrian V., 2003, Optimization approach to determine interval velocities in a medium with laterally inhomogeneous curvilinear layers, SEG Convention, Dallas, Expanded abstracts.
Blias E., 2005, New VSP Wavefield Separation Method. Wave-by-Wave Extraction, CSEG National Convention.
Galperin E.I. Vertical Seismic Profiling, 1971, Moscow, Nedra.
Hardage B.A., Toksöz M. N. and Stewart R. R. 1983-1984, Vertical seismic profiling, Geophysical Press, London.
Salo E.L., Schuster G.T., 1989, Traveltime inversion of both direct and reflected arrivals in vertical seismic profile data: *Geophysics*, 54, p. 49-56.
Thomsen L. 1986, Weak elastic anisotropy, *Geophysics*, 51, 1954 – 1966.