UDC 550.834.53

EXAMPLE OF AN APPROACH TO EVALUATION OF LATERALLY VARIABLE SEISMIC WAVELET

V.N. Smirnov [1], A.V. Novokreshchin [2]
Tyumen Petroleum Research Center ("TNNC" LLC), Tyumen, Russia
e-mail: [1]vnsmirnov2@tnk-bp.com, [2]avnovokreschin@tnk-bp.com

Abstract. *One of the most critical parameters affecting the quality of interpretation of seismic data and seismic inversion procedures is a seismic wavelet, as well as stationary of its areal features. The article offers an approach to evaluation of laterally variable wavelet parameters and also map evaluations in case of analysis by 3D seismic data.*

Keywords: *seismic wavelet, deconvolution, autocorrelation, amplitude-frequency spectrum, peak frequency*

The quality of time cross sections and thus the applicability of obtained seismic and geological models depend on exploration environment, as well as on the value of consideration of different factors distorting field data processing. These factors are listed as follows: topographic conditions, near-surface lithological variations, weathering or permafrost thickness, lateral variations of source wavelet and energy, high-frequency noise (for example, wind), coherent noise (ground roll and multiple waves, etc.), noise and distortion of the receive path, seismic energy absorption by the environment, geometrical variations of the seismic acquisition system, etc. [1].

One of the most critical parameters affecting the quality of interpretation of seismic data and seismic inversion procedures is a seismic wavelet, as well as stationarity of its areal features. The wavelet may exert special influence on the result of seismic inversion. Energy transfer from the main lobe to side lobes of the wavelet results in the addition of medium frequency component to the reconstructed impedance distribution curves; the noncomformity of phase spectrum may result in the reconstruction of nonexistent streaks on the boundaries of seismically thick layers [2]. Such effects may be observed if on the stage of field data processing the lateral wavelet parameters were not brought to common form, and on the stage of seismic inversion the characteristics of used wavelet were not corresponded to every single trace. All of this leads to incorrect structural and dynamical interpretation of seismic survey data.

Strong variations of wavelet characteristics are observed in the transition zones, where the sources and receivers need to be changed at the transition from land to shallow marine zone. In this case, the two-stage statistical deconvolution (for common source gather and common receiver gather) can be suggested [3]. Near-surface lithological features deform the wavelet, whereas velocity heterogeneities lead to variations of wavelet peak frequency [4]. Not always such effects are eliminated, therefore on the time sections there are zones of non-geological changing of dynamic characteristics (Fig. 1).

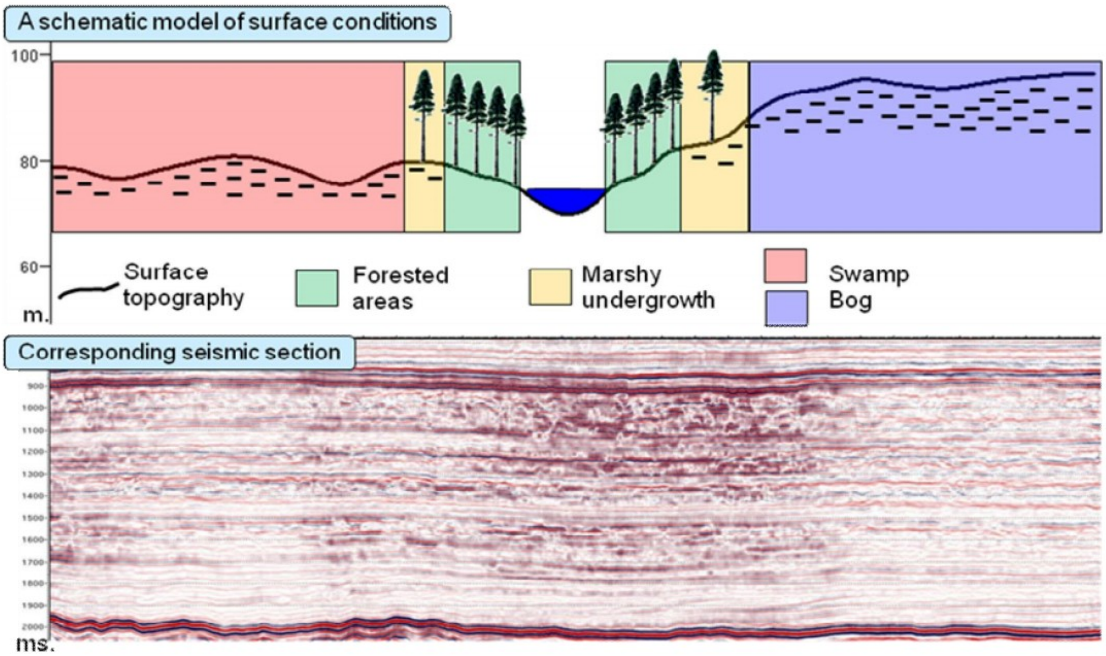

Fig. 1. Schematic model of near-surface conditions and corresponding time section

Changing of surface conditions in case of land survey, such as presence of sand dunes with different thickness [5], or lateral lithological variations in near-surface complex, results in different wavelet characteristics, although elastic wave sources have identical parameters. Good, but uncommonly used example of eliminating these distortions is carrying out the development works to find how the wavelet parameters change depending on source characteristics (for example, mass of the explosive) and lithology of shot environment. Obtained information allows to vary the parameters of seismic source for the area with lithological heterogeneity, as a result, the features of the seismic wavelet become stationary within the area [6].

Usually there are the situations when the dynamical characteristics of seismic record and, correspondingly, the wavelet parameters are influenced by local subsurface heterogeneity, such as gas cap [7]. In this case the influence of gas should be excluded. The AGC procedure in wide window [7] is not preferable and may significantly distort the dynamic characteristics of seismic wavefield. The most preferable in these situations is using the procedures of Q-compensation [8].

It is quite obvious that the distortions described above should be evaluated and taken into account either on the phase of processing/postprocessing of seismic data or on the phase of inversion transformation by using laterally variable wavelet [2, 13, 14]. Spatial variations of the wavelet can be obtained by using statistical autocorrelation [1].

The example of this approach is implemented in the plugin “ELVI” (auth. V.N. Smirnov, A.P. Devyatka) for Schlumberger software Petrel and represented in Fig. 2.

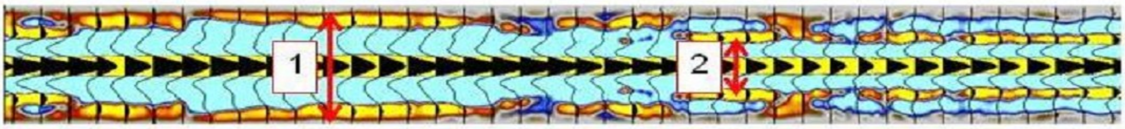

Fig. 2. Using of autocorrelation of seismic traces in the target interval for the evaluation of wavelet areal stationarity:
1 – zone of low-frequency wavelet; 2 – zone of high-frequency wavelet

It can be observed that the characteristics of the wavelet change from low (Fig. 2-1) to high frequency (Fig. 2-2). However, if 2D data can be easily analysed, then for 3D data, due to large volume of data, it is necessary to obtain lateral estimate of wavelet parameters variation.

There are a variety of spectral decomposition methods: maximum entropy method (MEM), continuous wavelet transform (CWT), matching pursuit decomposition (MPD) and discrete Fourier transform (DFT) [9]. The preferred is DFT which was calculated trace-by-trace from autocorrelation cube. After that was used three different estimates (Fig. 3) for mapping of wavelet parameters lateral variation. Here the most important is peak frequency.

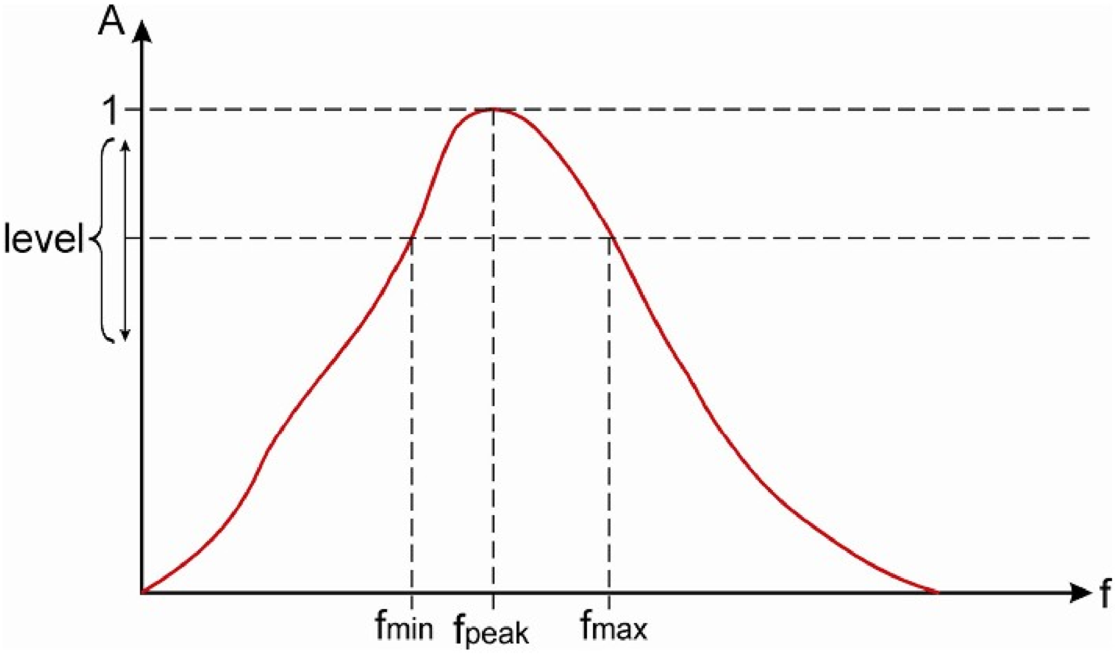

Fig. 3. Normalized to «1» amplitude-frequency spectrum and three estimates: peak frequency (f_{peak}), minimum frequency (f_{min}) and maximum frequency (f_{max})

It is worth noting that in Russian Federation national standard 24346-80 the parameter which corresponds to “frequency which corresponds to the maximum amplitude in spectrum” is termed as dominant frequency. Meanwhile, dominant frequency denotes square root of the second moment [10] and peak frequency denotes frequency corresponding to the maximum amplitude in spectrum [11]. In this work we shall use the term “peak frequency”. This parameter is responsible for the main lobe of seismic wavelet.

For trace-by-trace calculation of these three frequency parameters there was used “Spectrum Qualifier” plugin (auth. V.N. Smirnov, A.V. Novokreshin, A.P. Devyatka) for Schlumberger software Petrel. As a result there were obtained three frequency maps (fpeak, fmax and fmin) which were consequently combined into one map with different weights. For example, weight 0.25 was used for fmin and fmax maps and 0.5 for f_{peak} map. Resulting complex map reflects the lateral changes of wavelet.

For example in Fig. 4 there displayed such complex map and the location of line from autocorrelation cube demonstrated in Fig. 2. In complex map two zones stand out: one with low-frequency wavelet (west part of map) and another with high-frequency wavelet (east part of map). This zoning is caused by patterns of seismic field survey. Zone with high-frequency wavelet corresponds to explosive seismic source and zone with low-frequency wavelet corresponds to vibrator source.

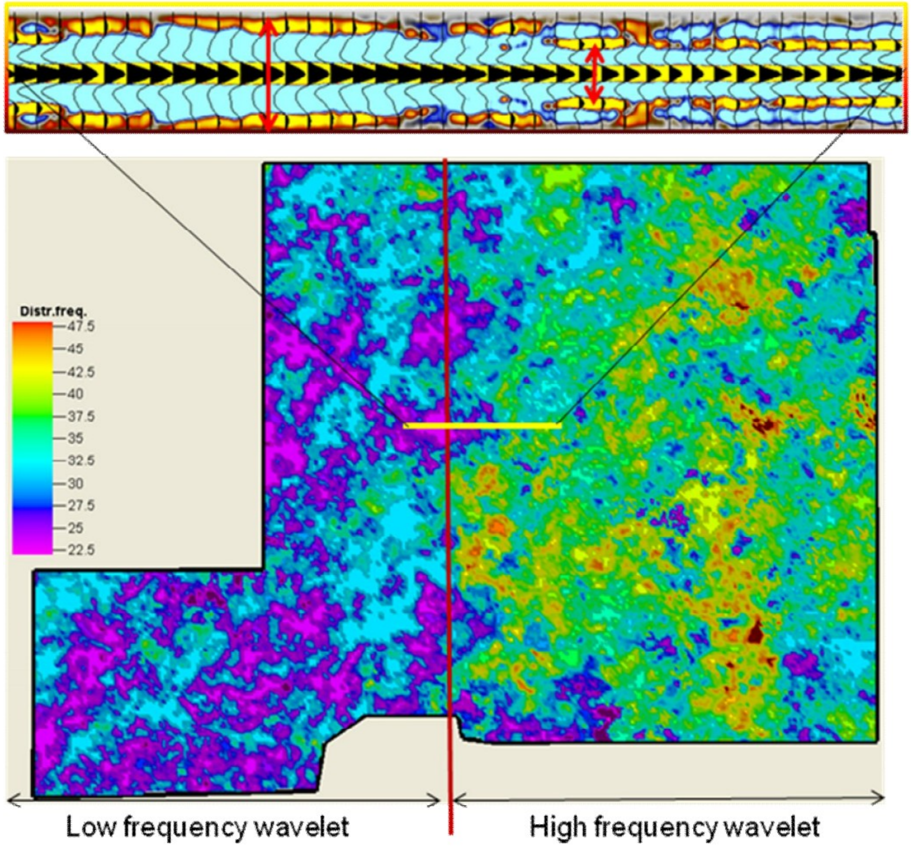

Fig. 4. Complex frequency map reflecting wavelet variation

In another example (Fig. 5), in the south-west of complex map the zone of underfrequency can be found out. This zone corresponds to slumpy peat bog which negates the parameters of seismic wavelet. It is known that unfunded deposits filter high-frequency according to high value of coefficient of absorption. Filtering action of 1500 meters thickness of terrigenous deposits is less than filtering action 4 to 5 meters of peat bog [12].

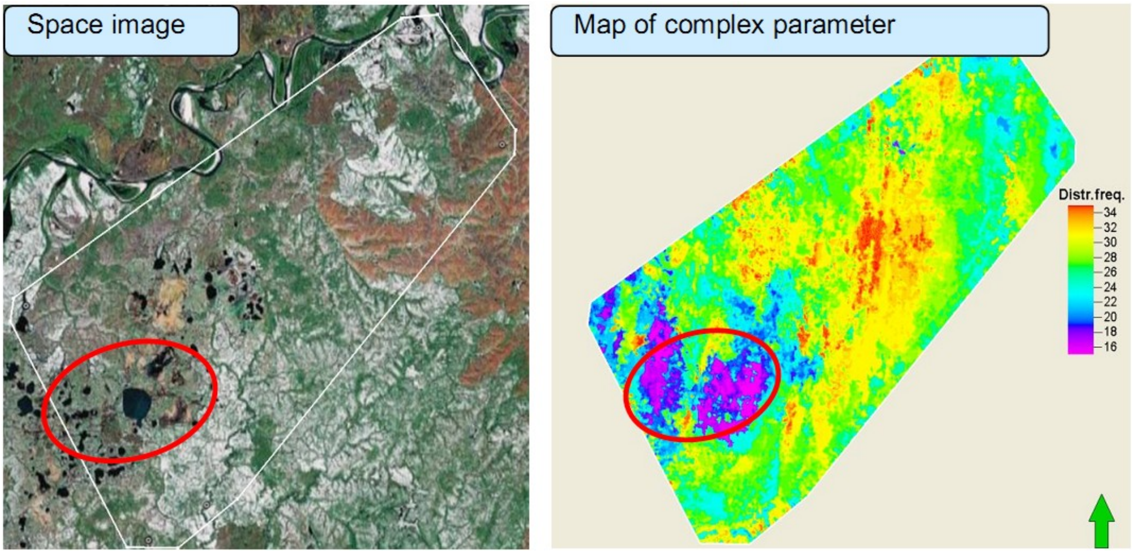

Fig. 5. The frequency map of complex parameter and space image of the field

It is evident that attribute analysis of seismic data or seismic inversion in such cases will give bad results due to variations of seismic wavelet parameters. Standard procedure for revaluation of wavelet parameters is a postprocessing, but the realization of this procedure is not always possible. In case of seismic inversion the another approach is possible by using cube of laterally variable wavelet. This approach gives good results both for model data [2] and for elimination of variations of excitation and receiving characteristics in case of transit zone seismic survey [13] or in gas deposits [14].

Conclusions

Due to wavelet influence on interpretation of seismic data there must be done an estimate of lateral variation of wavelet. This variation may be influenced by many different factors. The main of these factors are surface environment and parameters of seismic survey. If wavelet parameters vary laterally, then seismic data should be postprocessed or interpreter should use laterally variable wavelet for seismic inversion.

References

1. Wu Lin, Ling Yun, and Guo Xiangyu. 3D seismic data monitoring and evaluation // SEG 73-rd Annual International Meeting expanded abstracts. Dallas, 2003. Vol. 22, pp. 2140-2143.

2. Smirnov V.N., Novokreshchin A.V. Smirnov V.N., Novokreshchin A.V. Peremennyi impul's dlya akusticheskikh inversionnykh preobrazovanii (Laterally variable wavelet for acoustic inversion). *Tezisy Simpoziuma «Tyumen'-2011. Produktivnye klinoformnye kompleksy i vozmozhnosti sovremennoi seismorazvedki» (Proceedings of symposium "Tyumen-2011 Productive clinoform complexes and modern seismic exploration potentials")*. Tyumen, 2011. PP. 2-3.

3. Jun Gao, Yun Ling, and Desheng Sun. Geophysical and geological QC in seismic data processing. *SEG Annual International Meeting & Exhibition expanded abstracts*. Beijing, 2009. Vol. 28, p. 625.

4. Congde Lu, Y. Ling, J. Gao, D. Sun, and J. Lin. Study of near-surface layer effects in reflection seismic exploration from the dynamics point of view. *SEG International Exposition and Annual Meeting expanded abstracts*. Houston, 2009. Vol. 28, p. 1414.

5. Yanbin G., Xiaoyun D. Desert seismic data processing technology from desert surface. *SEG Annual Meeting expanded abstracts*. New Orlean, 2006. Vol. 25, p. 566.

6. Gao Guocheng, Shi Haifeng, Wang Naijian and Liu Yangui. Method to preserve wavelet consistency in high-precision seismic exploration. *SEG Annual Meeting expanded abstracts*. New Orlean, 2006. Vol. 25, p. 80.

7. Bacon M., Simm R., Redshaw T. 3-D seismic interpretation. Cambridge: Cambridge University Press. 2003. P. 156.

8. Wang Y. Inverse Q-filtering seismic resolution enhancement. *Geophysics,* 2006, Vol. 71, No. 3, pp. 51-60. DOI: 10.1190/1.2192912

9. Castagna J.P., Sun S. Comparison of spectral decomposition methods. *First Break*, 2006, Vol. 24, No. 3, pp. 75-79.

10. Barnes A. Instantaneous spectral bandwidth and dominant frequency with applications to seismic reflection data. *Geophysics,* 1993, Vol. 58, No. 3, pp. 419-428. DOI: 10.1190/1.1443425

11. Kallweit R., Wood L. The limits of resolution of zero-phase wavelets. *Geophysics,* 1982, Vol. 47, No. 7, pp. 1035-1046. DOI: 10.1190/1.1441367

12. Bobrovnik I.I. Vliyanie verkhnei chasti razreza na formirovanie seismicheskogo signala (Near-surface influence on wavelet shaping) in *Geophysical compilation of ZapSibNIGNI papers*. Tyumen, 1971. Vol. 25. P. 14.

13. Knyazev D.I., Rodina O.A. Raschet i primenenie peremennogo po ploshchadi impul'sa dlya seismicheskoi inversii (Calculation and application of laterally variable wavelet for seismic inversion). *Tezisy 11-oi mezhd. nauch.-prakt. konf. "Geomodel-2009"* (*Abstracts of 11th Intern. research-to-practice conf. "Geomodel-2009"*), 2009.

14. Rudiana C., Irawan B., Sulistiono D., Sams M. Overcoming seismic attenuation caused by shallow gas above at a gas field offshore Indonesia to quantitatively characterize the reservoir through simultaneous inversion. *Proceedings of 32nd Annual IPA Convention & Exhibition*. Jakarta, May, 2008. IPA-G-134.