Introduction

The application scope of spectral methods in interpretation of seismic data is quite extensive: spectrum time analysis (STAN) for regional sedimentation studies (Mushin, 1990), spectral decomposition for research of local objects (Partyka G., 1999), and amplitude versus bandwidth (AVB) method for identification of sedimentation features in local zones (Kelly M., 1992). This article describes these three methods.

STAN method is used in regional sedimentation for identification of geological cycles in the seismic data (Vail P.R., 1977) and matching them with geological sequences. It is known that geological processes are cyclical, but have different periods (ranks). High rank shows up in the high frequencies component of seismic trace and low rank in the low frequencies (Kozlov E., 2007). STAN is based on filtering the seismic trace using several central frequencies, grouping filtered traces in order to increase central frequencies of the filter (STAN column), and analyzing the resulting ensemble of traces (STAN-columns) in order to detect changes in geological rank (Mushin I.A., 2000).

One of the most common methods used for the qualitative analysis of thin layer thickness is called spectral decomposition (Partyka G., 1999). There are many different ways to transform from time to frequency domain. Three of the most widespread methods are Short Time Fourier transform, wavelet transform and matching pursuit algorithm (Chakraborty A., 1995). Short-Time Fourier transform uses the constant and limited time interval and as a result the resolution in the frequency domain depends on the size of this window and a constant. In order to overcome these window and constant limitations, a method based on the wavelet transform was developed. In this method the window function is a wavelet with a changing frequency, which allows for higher resolution at high frequencies (Sinha S., 2005). However, all windowed time-frequency transformations have limitations and as a solution a matching pursuit method (Liu J., 2006) independent of window function was developed. In this method, suitable wavelets are selected from predefined dictionary of wavelets by the least-squares algorithm. Considering that there are many linear combinations of wavelets for one trace, it is necessary to add the prior information about the signal (like instantaneous frequency and phase) in order to provide perfect resolution.

AVB method is applied to distinguish layers with constant properties from gradient properties. It is based on studying change in amplitude of the reflected wave depending on filter’s bandwidth, that is applied to the seismic trace.

Method

STAN

Based on lithospheric plates tectonics, it is logical to propose that the process of sedimentation is cyclic (Vail P.R., 1977). The cyclic structure of the lithological section is expressed in periodic changes of reflection coefficients. STAN method is used to distinguish hidden periodicity in seismic data.

Cycles of geological structure respond to consistent frequency changes in seismic trace and are best observed in a certain frequency range. STAN accentuates these variations by filtering seismic traces through bandpass filters with different central frequencies and arranging them in order of increasing frequency. The resulting column of traces is called the STAN column (Figure 1.a). The shifting of energy in STAN-columns is related to types of cycles: procyclites and recyclices (Figure 1.b) (Kozlov E., 2007). These cycles correlate with transgressive and regressive types of sedimentary, because usually thin layer sequences are created by shale intercalations.
Figure 1 An example of a seismic trace (a.1), its corresponding reflection coefficients (a.2), and a SWAN column (a.3). Types of cycles and their corresponding swan columns (b).

Spectral decomposition

Spectral decomposition is a method used to detect more local geological objects and identify their properties. This method is used to identify paleochannels’ boundaries and variation of their thicknesses using RGB blending (Liu J., 2007). There are three the most widespread methods based on different algorithms: Short Time Fourier transform (STFT), continuous wavelet transform and matching pursuit. All these algorithms can be effectively used with different time-frequency resolution (Chakraborty A., 1995). To accentuate the thickness variations it is better to use STFT or continuous wavelet transform because they transform the trace directly to frequency domain without prior information. But method based on matching pursuit request the prior information (usually instantaneous frequency and phase) that is why before using this method it is easy to predict the result by testing the prior attributes, and if geological objects show up at the instantaneous attributes then the matching pursuit algorithm will be effective. In order to detect thin paleochannel boundaries it is effective to use RGB blending because thin layers change the amplitude of reflection at the different angles and also change the frequency as the same time (Juhlin C., 1993).

AVB

The Amplitude versus bandwidth method (AVB) consists of analyzing filtered trace’s amplitude by using filters with different passband at a certain point in time (Kelly M., 1992). This method is used to distinguish thin layers with constant contrast properties from gradient layers (Liner C., 2010). In this method the trace is filtered at different frequencies and the filter passband increases with central frequency. Then the amplitude from every filtered trace is removed at certain time sample and the dependence of this amplitude on passband is found on AVB plot. There are two ways to analyze the plot: the first one is computing a linear trend, determine the angle between the abscissa and ordinate (w0) (intercept) and an intersection with the ordinate axis (w1) (gradient), and the second one is calculating a straight line from the maximum point of the plot to the constant meaning point (the line from the second method illustrated in the figure 2) (Alekseeva P., 2018). If the gradient of the second line has negative number then this layer could have gradient properties (Figure 2).

Results

The described methods were applied using 3D seismic data in the West Siberian region. The STAN method divided the seismic field into different zones which corresponded with transgressive and regressive system tracts and well data. This method simplifies correlation between
seismic horizons and well ties, because it matches the stratigraphic hierarchy with seismic features. It helps to identify sequence boundaries and the maximum flooding surface.

Three types of spectral decomposition methods were applied to detect paleochannels and identify their properties. According to the results of spectral decomposition, the methods based on STFT and MP were the most useful for mapping boundaries of the channels and describing the channels’ properties (qualitative analysis of thicknesses). To detect the boundaries of the paleochannels, it is effective to combine RGB mixing of different frequencies with information about angular sums, because the changes in the channels’ thickness causes the change in both the reflection coefficient and in the dominant frequency. During qualitative assessment of the channels’ thicknesses, the inclusion of both cubes of angular sums make interpretation more difficult. Therefore, RGB mixing of only frequencies was used for properties analysis (Figure 3).

The AVB the method mapping local facial zones using the straight line passing through the maximum value of the AVB plot and the point of constant meaning. The map of the AVB gradient divided the channel into different facies zones.

![Figure 2 AVB Plots (1) for layers with different thickness and corresponding sections of gradient attribute (2) for three types of layers’ structure (a,b,c)](image)

![Figure 3 The sequence of spectral methods: a) STAN (Spectrum-time analysis), b) Spectral decomposition (RGB blending of frequencies and different angles), c) AVB (amplitude versus bandwidth)](image)
Conclusion

In this work, three methods of spectral analysis were studied. Application of the STAN method is applied in regional sedimentation analysis, it is facilitated stratigraphic differentiation of seismic data, identification of erosion boundaries and maximum flooding surfaces, and determination of the regional nature of sedimentation (transgressive, regressive).

Spectral decomposition methods distinguish channels’ boundaries and qualitatively determine their thickness. Three spectral decomposition methods were mentioned in the paper and all of them have their own benefits and could be used in seismic interpretation. The AVB method distinguished different internal properties of thin layers, which makes it possible to identify zones for facies mapping of gradient and contrast geological objects whose properties are difficult to distinguish by standard interpretation methods.

References


