The adaptive vibroseis technology: hardware, software and outcomes

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Summary

The adaptive vibroseis technology offers a way to improve seismic survey resolution and signal-to-noise ratio. This technology employs nonlinear sweep signals that are adjusted/adapted to match the near-surface environment at each source point. The automatic adjustment of the sweep signal to match changes in source point environments along the shot line expands signal spectra and, accordingly, results in better reflection resolution, as well as in more consistent signal shapes and amplitudes along the survey line. The adjustment is introduced in real time and has virtually no effect on the progress of field surveys.

Introduction

The ever growing expectations of exploration geologists regarding the level of detail and validity of geological models, and greater reliance on geophysical data (mostly 3D seismic), oil shale exploration, and the increased interest in shallow petroleum reservoirs have resulted in more stringent standards of seismic data resolution.
We are witnessing continuous improvements in seismic data accuracy achieved through better processing technologies (an array of deconvolution algorithms, spectral expansion, etc.). However, no matter how good a processing algorithm may be, we are likely to face great difficulties in obtaining high resolution stacks, unless we manage to ensure acceptable signal-to-noise ratios across the entire source signal spectrum.
Moreover, improving the accuracy of amplitude analysis requires adjustments to the frequency and amplitude of the source signals in order to mitigate spectral interferences introduced by near-surface heterogeneities.
Certain approaches have been developed to increase the high-frequency component of the sweep signal. First of all, they include the use of nonlinear sweep signals that is based on a disproportional increase of duration of high-frequency generation at source points (Zhukov, Shneerson, 2000). The main challenge to the practical implementation of this approach is the inefficiency of manual nonlinear sweep adjustments needed to match the changes in the subsurface. In most cases only one fixed nonlinear sweep signal, set based on a test area environment, is used over the entire survey area. This often results in less than optimal outcomes in some areas. The adaptive vibroseis technology (Zhukov et al., 2011) can overcome this challenge. This paper presents some practical aspects of the technology.

Adaptive vibroseis technology

The technology essentially lets us automatically select and apply nonlinear vibroseis signal parameters in real time and partially mitigate attenuation effects based on an analysis of frequency-dependent seismic signal attenuation and set optimization criteria (such as the highest resolution for a given frequency range and time interval).
Needless to say that such optimization criteria may vary. They may include, for example, resolution and SNR to optimize signal stacking and horizon picking, etc.
To support this approach, we have developed the vibroseis source control unit. In addition to a comprehensive set of essential vibroseis source control functions, this unit incorporates the required software for automatic real-time reflection spectrum monitoring, generation of an adjusted nonlinear sweep signal and source firing. Thus, we apply the deconvolution and spectral expansion procedures to the actual vibroseis source signal to mitigate the filter effect of near-surface heterogeneities.
The adaptive vibroseis technology implementation scheme is shown in Figure 1.

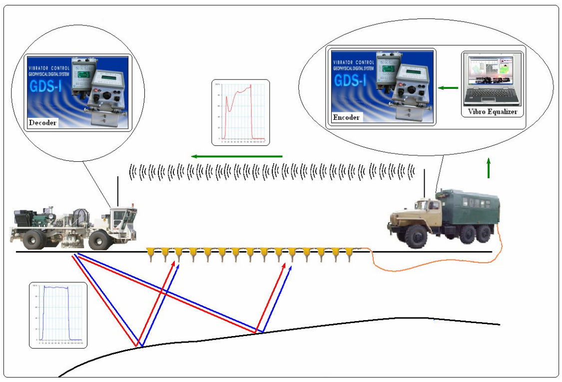

Figure 1: The adaptive vibroseis technology operating principle.

The first shot at each source point uses a linear sweep signal with a set frequency range. The resulting seismic record within the selected reflection window is used to calculate amplitude spectrum and corresponding deconvolution-like scalars . The sweep signal obtained from such deconvolution is used for the next shot. Thus, all subsequent shots at given source are adapted to spectral characteristics of the target interval.

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A comparison of correlated records and their spectra that were obtained using linear and adaptive sweep signals within Moscow syneclise is presented in Figure 2. It is obvious that the adaptive sweep signal results in a greater high-frequency component and more consistent spectra.

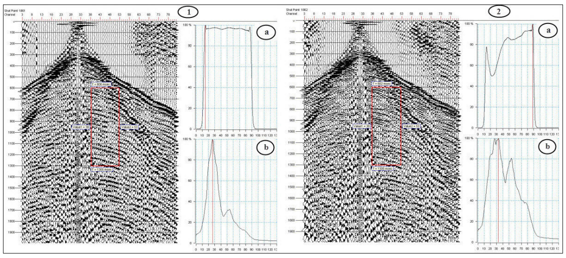

Figure 2: Correlated vibroseis records and their spectra (a - sweep spectrum, b - reflection spectrum). (1) - linear sweep, (2) - adaptive sweep.

The white-noise level set as a percentage of the maximum amplitude for a seismic record is a key setting of an adaptive vibroseis system. This parameter adjusts the degree of deconvolution of the recorded seismic signal, just like in any deconvolution procedure used in seismic data processing software. The lower is the set white-noise level, the greater is the adjustment. This is illustrated by Figure 3. The linear sweep signal spectrum for a given frequency range, the reflection spectrum with losses introduced during signal travel through the interval, and adapted sweep signal spectra for various noise settings are shown in Figure 3-a, and the reflection spectra corresponding to various source signal settings are shown in Figure 3-b. As the noise level decreases, the high-frequency component increases.

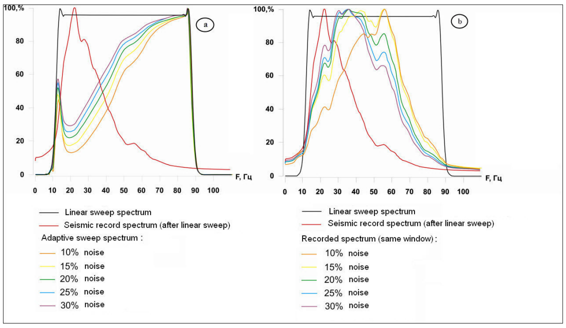

Figure 3: Spectral variations of emitted sweep signal (a) and data recorded (b) depending on adaptive control settings (white noise levels).

Testing includes selection of the two main setting of the automated sweep control system, i. e. the frequency range and white-noise level, while taking care not to increase the noise in the high-frequency range.

Examples

The adaptive vibroseis technology has been successfully used in many areas of Russia.

Figure 4 represents the results of a conventional 3D survey (400 m spacing for both source and receiver lines) and high-density adaptive vibroseis survey (200 m spacing for source lines and 100 m spacing for receiver lines). To illustrate the net effect of the adaptive vibroseis technology only, the data has been "rarified" to match the conventional grid spacing (Figure 4-b). The combined effect is shown in Figure 4-c.

Figures 5-6 show a significantly higher resolution for mapping small faults on both time slices and stacks.

Conclusions

The adaptive vibroseis technology helps us achieve a much greater degree of detail across the entire survey area and, accordingly, to build a more adequate reservoir model.

When designing a vibroseis survey program, one should remember that, depending on soil stiffness and plate-soil interface conditions, there may be sharp variations in amplitude and frequency behavior of the vibrator-soil system along the survey line. Thus, it is clear that to improve to accuracy of vibroseis surveys, it is critical to use vibrators with advanced control systems that provide both phase and amplitude-frequency adjustments to the source spectrum based on an analysis of the recorded spectrum.

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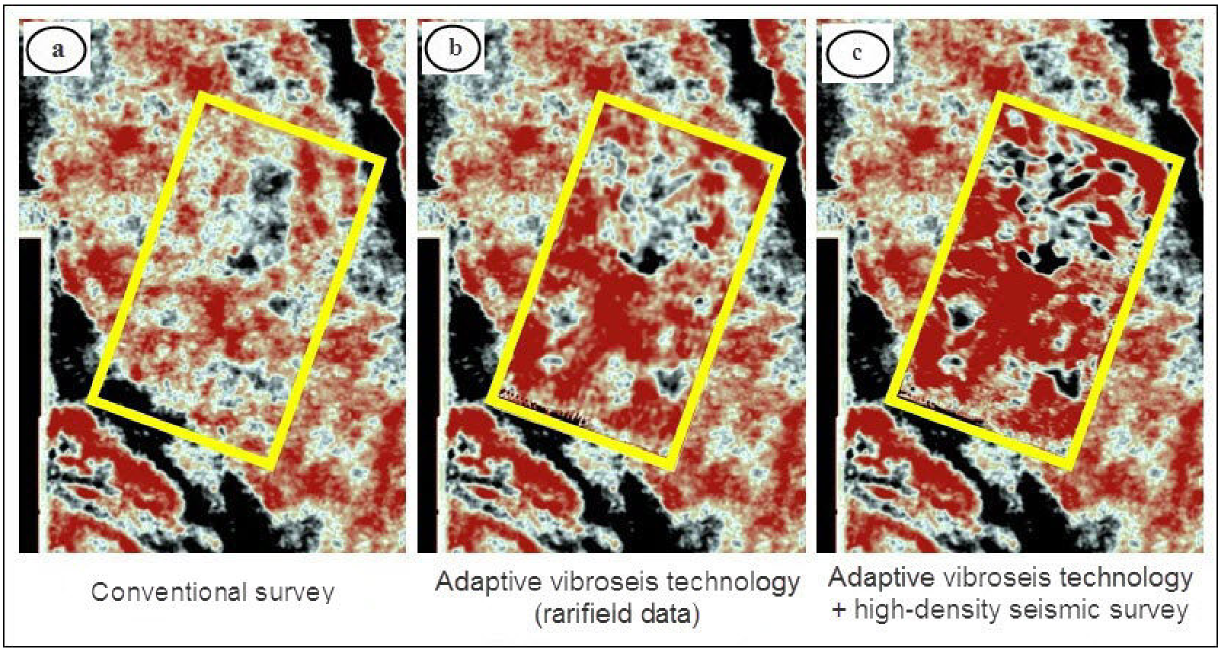

Figure 4: 3D time slices corresponding to a Cenomanian reservoir. From left to right: conventional technology (a), adaptive vibroseis technology (b), high-density seismic survey + adaptive vibroseis technology(c).

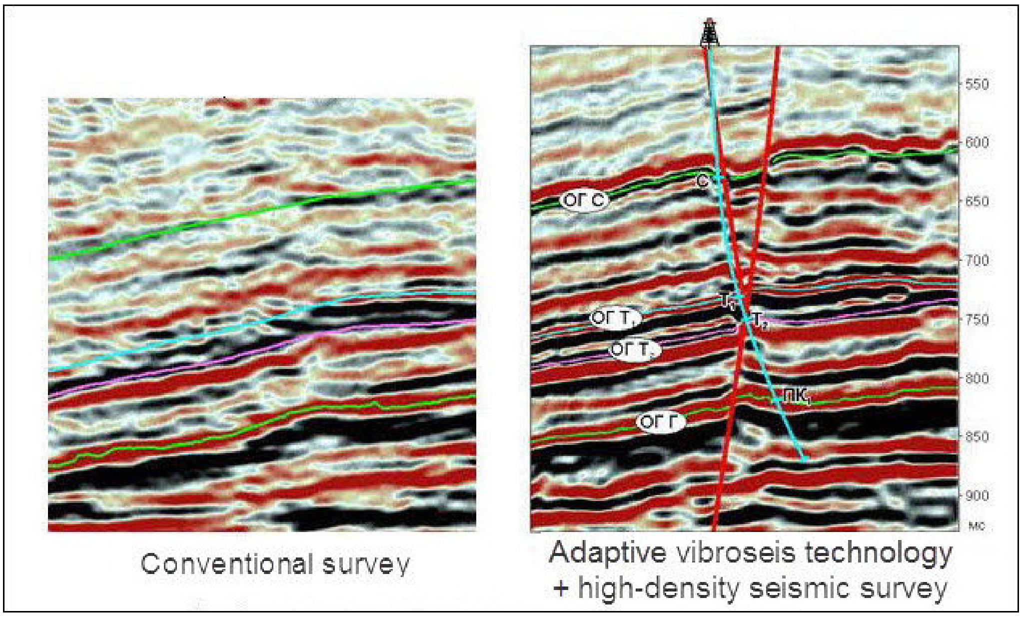

Figure 5: Example of better faults imaging with adaptive vibroseis technology (on the right).

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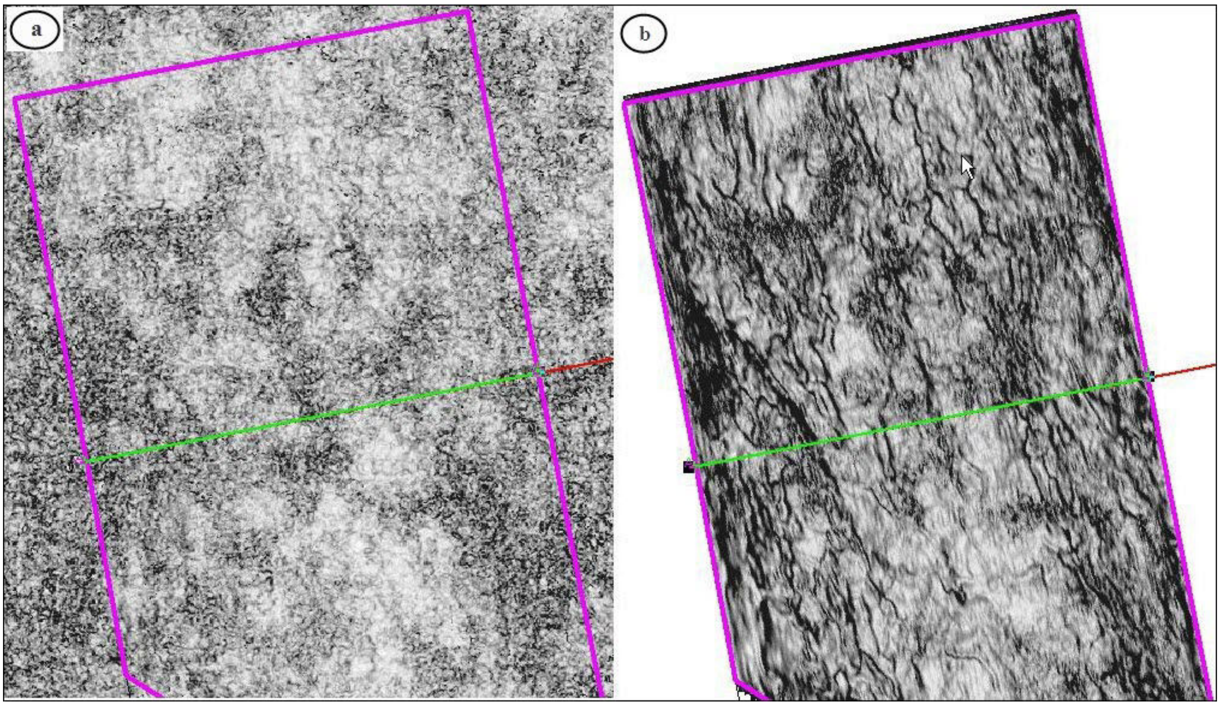

Figure 6: Coherence cubes. (a) - conventional survey, (b) - adaptive vibroseis technology + high-density seismic survey.

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EDITED REFERENCES

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