Technology of Adaptive Vibroseis for Wide Spectrum Prospecting

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Abstract: Seismic data from conventional vibroseis prospecting is characterized by narrow frequency bandwidth due to earth absorption. This article introduces a technology of vibroseis prospecting, which is based on automatic optimizing of sweep parameters for the actual data and designs different sweep length for different frequency, thus increases the exciting energy of the middle to high frequency signals, and enhances the s/n ratio of middle to high frequency components. Furthermore, processing is done on low frequency protection and extend high frequency according to the features of the AVISeis data, thus achieves the purpose of extending effective bandwidth of seismic data. This method is wide spectrum prospecting, which increases the ability to identify thin interlayers and lithologic reservoirs.

Keywords: Vibroseis, nonlinear sweep, adaptive sweep, resolution, s/n ratio

1. Introduction

Along with the stronger requirement for safety and environmental protection, green prospecting with vibroseis has become the main method for land prospecting. This is more the situation with the presence of low frequency vibrators, whose start frequency is extended to 3Hz[1], and low frequency information is improved effectively. However, because of the absorption affecting by loose layers of the near-surface, high frequency signal is attenuated severely, so makes limitation to the ability of high resolution by vibroseis prospecting.

The sediment of quaternary system in north China is rather thick, and the surface layer is loose. Great deal of underground water is pumped by industry and agriculture, leading to abrupt change of LVL horizontally. Past seismic data shows that the absorption of 60hz signal could reach 30-60db after it has passed through the surface layer. Because of the serious absorption in middle to high frequency seismic wave, seismic data's high frequency in the past could only reach 50hz. With the birth of non-linear sweep vibroseis technology, the results of linear sweep are improved, so is for the middle to high frequency component in some extent [2,3]. However, the parameters for non-linear sweep are determined by only several testing points, thus could not adapt for those areas with severe horizontal changing

in surface layer conditions, so fails to achieve the purpose of extending bandwidth of seismic data.

2. Basic method

The method of adaptive vibroseis (AVISeis) is to calculate different sweep parameters for different frequency according to each shot point's seismic record by linear sweep. Nonlinear sweep signal is designed one by one source point, so to increase middle to high frequency energy, and to receive middle to high frequency reflection signals from the target layers. Wider spectrum raw data is acquired. Through low frequency protection and high frequency extending, seismic data's spectrum width is further expanded, thus to achieve wide spectrum prospecting.

Principle of the adaptive sweep technology: analyze frequency band's absorption degree by analysis of the spectrum of linear sweep's record, and design nonlinear sweep signal for each shot point. In this way every shot point's sweep signal is optimized, and wide spectrum data is obtained.

Signal design formula could be expressed as:

$$S(f)avis = \frac{1}{S(f)response + \alpha}$$

here α is the adaptive coefficient for the whole area, S(f)avis is adaptive sweep signal's amplitude spectrum, and S(f) response is amplitude spectrum of seismic record by linear sweep of the same shot point.

The design of the adaptive sweep signal is to adjust each frequency range's sweep length according to the range's spectrum power. To compensate the absorption of the ground, less sweep time is to assigned to low frequency's sweep time, and more to high frequency, thus to achieve increasing of high frequency energy. Analysis of the same point's spectrum of records by linear and adaptive sweep shows adaptive sweep signal could excite more high frequency energy than linear sweep signal, and increase high frequency component's s/n ratio, thus acquire raw data with wider spectrum.
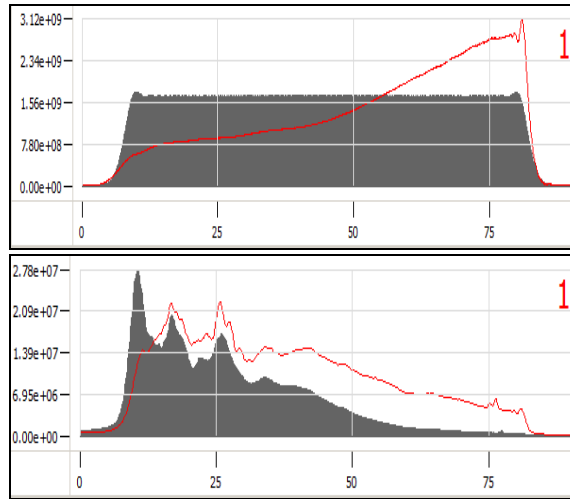
Fig. 1　Amplitude spectrum of adaptive (red) and linear records (shadowed)

For the same sweep parameters, compared with common linear sweep, low frequency information of data by adaptive sweep is relatively weaker, so low frequency protection must be done in data processing. The protection is based on high fidelity prestack de-noise which is of low frequency protection. The main method is data-driven low frequency compensation. A match coefficient is calculated according to the real data, then perform trimming processing. Wavelet's low frequency amplitude spectrum is strengthened, but phase spectrum is not altered. Doing this way achieves the purpose of strengthening low frequency information, and keeping the data's real features.

High frequency extension is mainly done by well-constrained deconvolution and structure-constrained Q compensation. Common deconvolution is performed by parameter selection according to parameter scan, comparing their effects in shot records and stack sections. Well-contrained deconvolution is to analyze the seismic trace beside the well with synthetic trace or VSP corridor stack, and to generate a series of matching attributes such as reliability, predictability, passing function and so on, and perform quantitative analysis and choose optimum deconvolution parameters. Stack section by well-constrained deconvolution could objectively mirror the reflection features of the horizons around the well.

The technology of Q compensation is to compensate the amplitude loss and phase distortion caused by earth absorption. It corrects the wavelet's stretching effect and compensates frequency and amplitude loss, thus enhances weak reflection's power, improves the continuity of events, and increases resolution of the seismic data. Q

compensation is actually a processing of anti-earth-filter.

Structure-constrained Q compensation is done according to the structure of the area by using sliding windows along horizons. Each horizon's Q model is formed by spectrum comparison. Interpolation and smoothing are performed to obtain a structure-constrained Q cube, then Q compensation is performed. Wavelet's energy attenuation is compensated, middle to high frequency's power is increased, and seismic record's resolution is improved.

3. Cases of application

Prospecting targets for area TKX are lithological traps in ES1 layer. The buried depth is between 1800 - 2500m. The thickness of the LVL layer in the area is between 12-25m. The layout for the 3D acquisition is 36L4S120R (36 spreads with 120 channels each, 4 shots between two detector lines). The binning is 25mx25m, and design fold is 360. Low frequency vibrator KZ28LF is used to make technological breakthrough for wide band prospecting with vibroseis. Sweep frequency is 1.5-84Hz. Two datasets are processed: one is adaptive sweep acquired data with fidelity processing, and the other one is linear sweep acquired data with regular processing. Two processing results are obtained.

Comparison of the raw records of the two datasets shows that main reflection horizons from both data are clear and visible (Fig 2). Visual frequency of adaptive data is obvious higher. For 6Hz low pass filtered record, both are equally the same, illustrating that adaptive data's low frequency components are not lost. 50Hz high pass filtered records shows that adaptive data holds high s/n ratio, meaning high frequency information is extended effectively. Spectrum analysis of different depth （time：0～1500ms, 1500-4000ms）shows that adaptive data is equivalent in low frequency band, and very remarkable in middle to high frequency band. For shallow layers the bandwidth is extended by about 20Hz, and for main target layers it is about 14Hz (Fig 3).
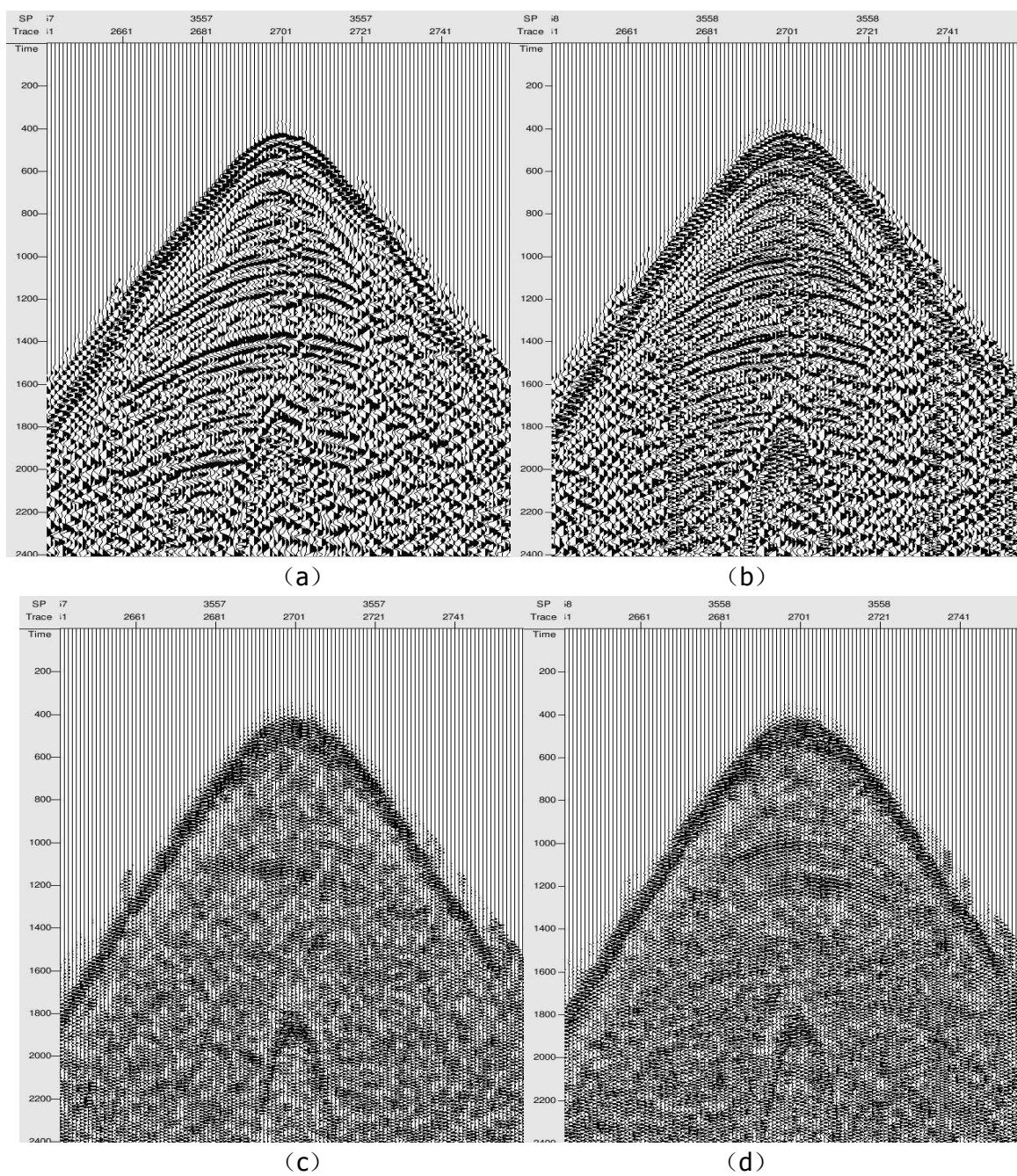
（a）　　　　　　　　　（b）

（c）　　　　　　　　　（d）

Fig 2. Raw records by linear sweep (a, c) and adaptive sweep (b, d)

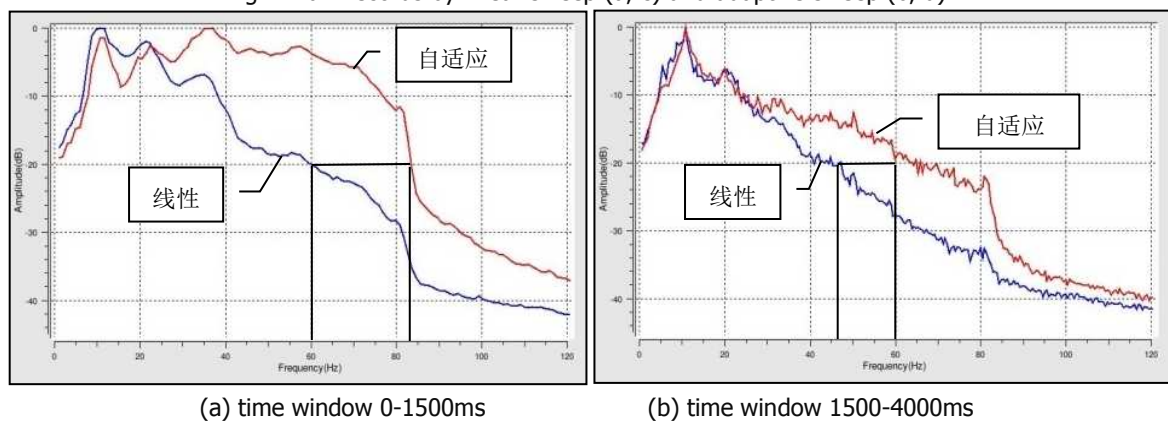(a) time window 0-1500ms　　　　　　(b) time window 1500-4000ms

Fig 3. Spectrum of raw records by linear sweep (a) and adaptive sweep (b)

In accordance with the feature of rich high frequency information in TKX area, firstly data-driven low frequency compensation is applied. This leads to enhancement of the low frequency components (1.5-6Hz) by more than 3db (Fig 4), and effectively protects low frequency information of the deep layers. The s/n ratio of deep layers increases considerably. High resolution processing is performed based on this result. Well Gao 1 is used to get synthetic trace to do cross correlation analysis with the beside-well trace with different parameter deconvolution. A set of matching attributes (like matching reliability, predictability, passage parameter, etc.) are generated for quantitative analysis and for selecting optimum parameters for deconvolution. After applying well-contrained deconvolution, frequency bandwidth is extended by 8-10Hz. Interpretation is undertaken using geological layers marked by drilled well. The deep zone is divided into 5 layers. Time windows are defined along layer for Q calculation for each layer, thus to get a Q cube for the whole area. After application of Q compensation, s/n ratio of middle to high frequency data in main target layers is further improved. The effective bandwidth of layer T4 is 1.5-60Hz, and the purpose of wide spectrum acquisition is achieved.

Comparison is made between two processing results for the main target layers, T4's overlaid special lithologic section and bottom sand below it (Fig 5). In wide spectrum data, the special lithologic section is clear and distinctive, the horizontal change could be traced, while in common data it's difficult to recognize the special lithological zone, and impossible to identify bottom sand. For spectrum comparison of the T4 layer, the energy of middle to high frequency in wide spectrum data is remarkably increased. The effective bandwidth is 8-10Hz wider than common data, and its effective frequency range is 1.5-60Hz.
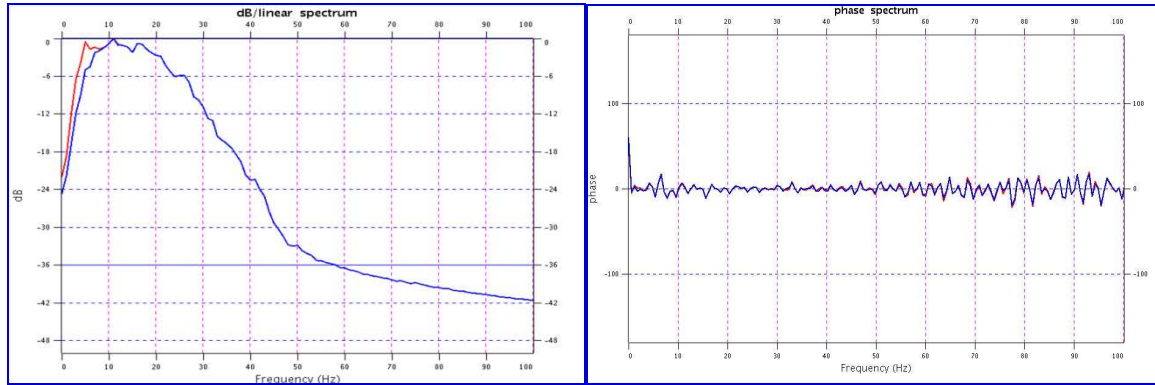
(a) Amplitude spectrum　　(b) Phase spectrum

Fig 4 Amplitude and phase spectrum before (red) and after (black) low frequency component

protection

Analysis is also done in impedance inversion section (Fig 6). Sand body in wide spectrum data is more continuous, and several period sand bodies are present with more information and higher resolution, while common data can only identify sand layers. According to well drilling data, around T4 horizon of well Gao 1, large sandstone body develops in special lithologic section and bottom sand section. The quantity of sandstone and mudstone predicted by rms attribute of wide spectrum data is agreed with the logging data, while it is a big error by common data. Using the 3D data from wide spectrum acquisition for sophisticated interpretation and reservoir prediction, a number of new lithological traps are found. Well GB1 is determined by wide spectrum data. 4m/1 layer of oil, 6m/2 layers of oil-water, 15m/1 layer of water, are found in Es1 period between 2359-2412m by logging, which matches the prediction before drilling. (Fig 7). This demonstrates that wide spectrum acquisition has some certain advantages in prospecting of lithological reservoirs.。
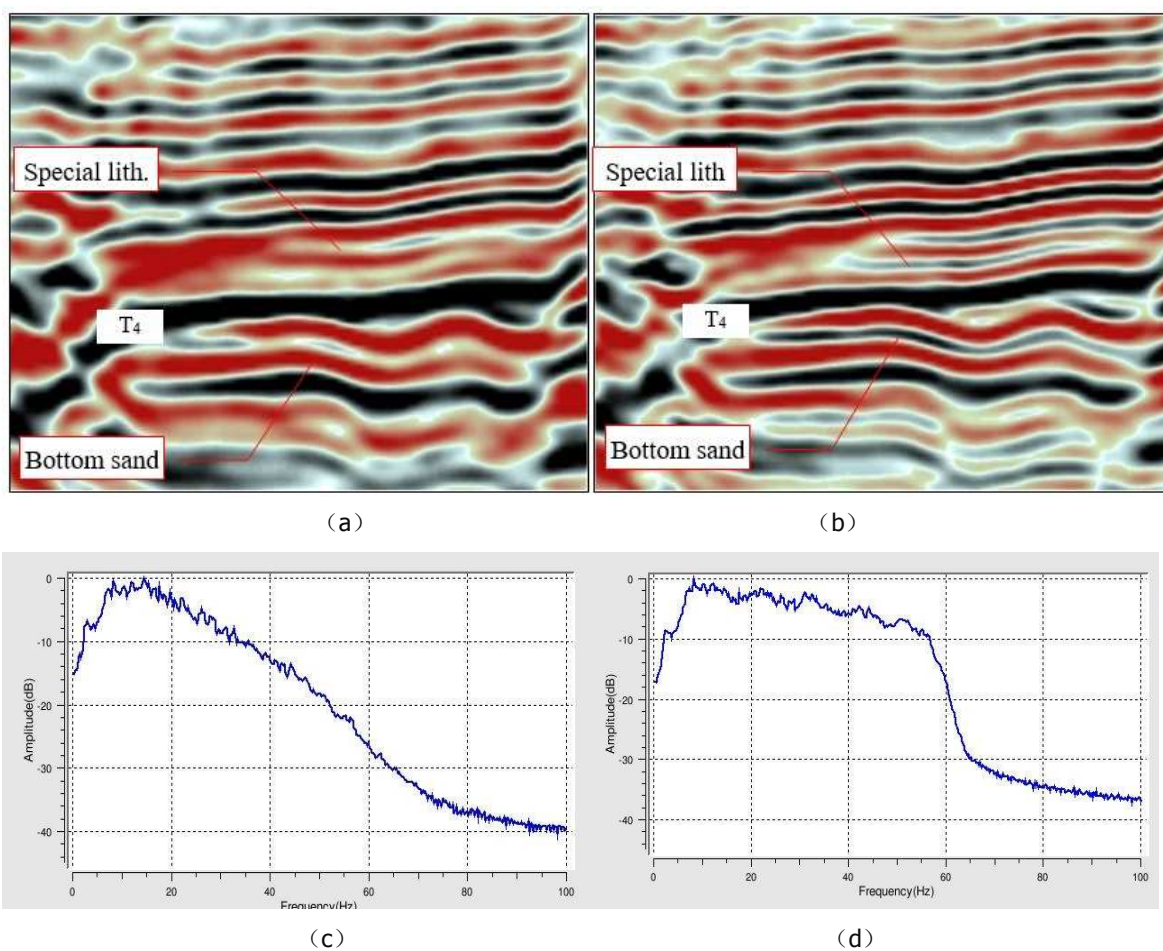
（a）
（b）
（c）
（d）

Fig 5. Sections and spectrums of target layers of common (a, c) and wide spectrum acquisition
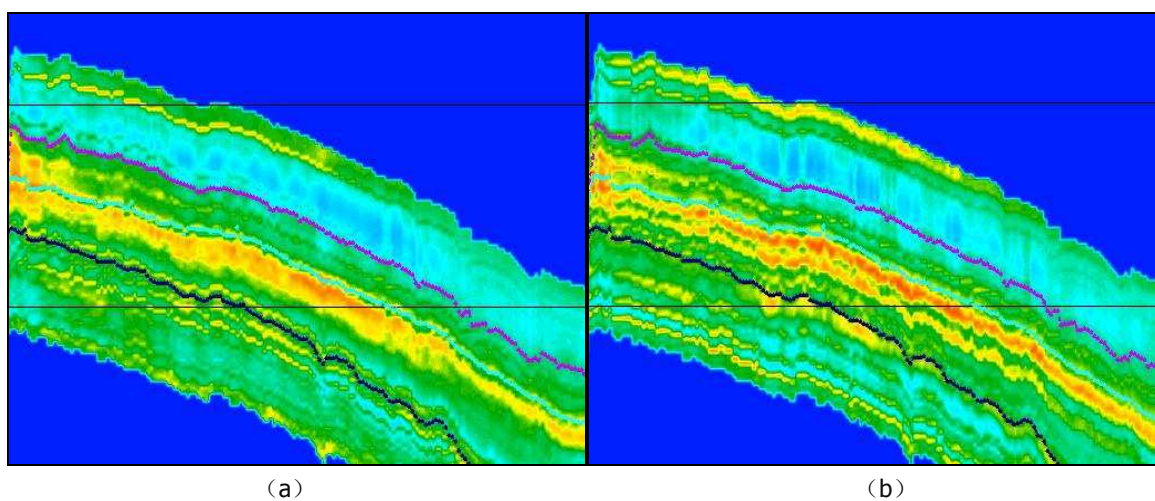

（a）
（b）

Fig 6.   Impedance inversion sections of common (a) and wide spectrum acquisition (b)
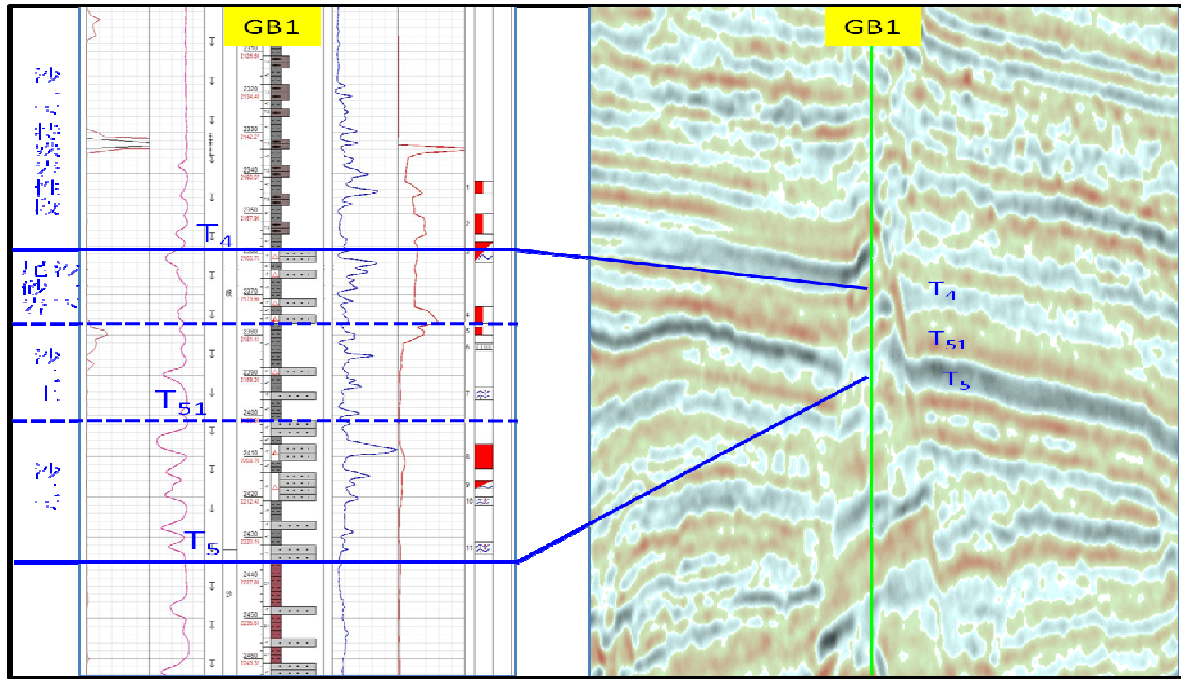
Fig 7. Well GB1 and wide spectrum section

4. Conclusion

The wide spectrum vibroseis technology is able to effectively expand the spectrum width of seismic data, and provide a new method for prospecting of lithological stratum. From its application in Huabei oil field, we get the following understandings:

1) Adaptive method with large tonnage low frequency vibrator is the basis for wide spectrum prospecting. Exciting energy in high frequency band is raised by automatic optimizing nonlinear sweeping. Raw data's s/n ratio for high frequency band is improved, thus raw data with wider band and higher s/n ratio is obtained.

2) The key processing point is hi-fi, data-driven low frequency protection and high frequency expansion, which will further extend the effective spectrum width of seismic data.

3) Wide spectrum acquisition is done by increasing high frequency energy of sweep and downward signals. Because of earth's severe absorption for high frequency, the valid prospecting depth by wide spectrum acquisition is adversely affected to some extent. 。

References

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