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An Effective Thin Reservoir Identification Method for Fine Oilfield Development

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Abstract

Thin reservoirs prediction method such as spectral inversion has drawn considerable attention in recent years. In order to avoid extracting wavelets within the whole field area purposeless and to make the filtered data has preferable fidelity as well as signal-to-noise ratio, an effective structural constrained thin reservoir description method which combines spectral inversion and wide-band Ricker wavelet filtering technology has been proposed in this paper. The method given here is more credible and is suitable for the prediction of middle-deep thin reservoirs. We take LD-A structure within Bohai Bay Basin as an example to show the implement of our method. Several sets of thin sand layers which are hardly to recognize originally have been finally identified. Also, with the application of this method, a high-production thin reservoir of LD-B structure has been identified accurately, which provides credible information for subsequent fine oil exploration and development.

Keywords

Structure Constrained, Thin Reservoir, Spectral Inversion, Wide-Band Ricker Wavelet, Exploration and Development

1. Introduction

On the basis of the Widess (1973) model, thin layers whose thickness bellows one-eighth dominant wavelength cannot be identified. However, with the rapid development of oil exploration and development, people find that some of the thin layers might be important oil bearing reservoirs and have high oil production capacity. Aiming to solve the above issue, spectral inversion has been proposed [1] [2] [3]. As described by Puryear and Castagna (2008) [4], in order to get a wide-band sparse-reflectivity cube, spectral inversion utilizes spectral decomposition to unravel the complex interference patterns created by thin-bed reflectivity. Then, after filtering processing on the reflectivity cube, we can study the thin reservoirs by imaging the data with a −90˚ phase rotation (Zeng and Backus, 2005) [5] [6].

Spectral inversion is a novel way of removing the wavelet form seismic data. (Chopra *et al.* 2009) [1]. Thus, how to extract precise and useful wavelets is of importance. However, as this inversion process does not require well constraint, the wavelets extraction step will be inevitable conduct purposeless within the whole seismic work area and the determination of the wavelengths should be test repeatedly.

Generally speaking, band-pass filter operator or Ricker wavelet is usually applied for filtering the reflectivity cube data. However, studies show that a type of wide-band Ricker wavelet composed of Ricker wavelets with different frequency parameters can better approximate the impulse function. This wavelet is characterized by narrow main-lobe, small side-lobe and simple waveform, and has preferable fidelity as well as signal-to-noise ratio (Yu, 1996) [7]. Also, it can provide with both wide-band and high signal-to-noise ratio in filtering progress.

Based on the previous studies, an effective thin reservoirs prediction method which combines spectral inversion and wide-band Ricker wavelet filtering has been proposed. This method has the following features: 1) In order to avoid extracting wavelets within the whole work area, we pay attention mainly on the potential reservoirs which usually locate in the high parts of the structure trap. The typical wells which hold representative feature of interesting structures will be taken for time-varying wavelets extraction. 2) Signal-to-noise ratio is used in the process of wavelets extraction, making the determination of the wavelets lengths much easier. 3) Before the structural constrained filtering, detailed comparative analysis of the spectrum characteristics of the original seismic data, the reflectivity cube data and the wide-band Ricker wavelet has been done. 4) The given method is more credible and is useful for middle-deep thin reservoirs.

We take LD-A structure within Bohai Bay Basin as an example to show the implement of our method. Several sets of middle-deep thin sand layers which are hardly to recognize originally have been finally identified. Also the method had been applied to LD-B structure successfully.

2. Theory and Method

Wavelets extraction of general spectral inversion method

Spectral inversion is a novel way of removing the wavelets form seismic data. (Chopra *et al.* 2009) [1]. Obviously, precise wavelets are very important for accurate spectral inversion. However, as this inversion process does not require well constraint, sometimes the wavelets extraction step will be conduct purposeless within the whole seismic field area. Take LD-A structure within Bohai Bay Basin as an example, **Figure 1** shows the structural map of H1 which represents an oil-formation of middle-deep Dongying. Where, the green and light green parts indicate the proven and controlled oil reserves respectively. The yellow part denotes the structural trap.

Traditional spectral inversion may extract wavelets according to the yellow points through the whole work area which will definitely bring in average effects for our target zone (The high parts of traps). Also, the determination of the wavelength should be tested repeatedly.

Wide-band Ricker wavelet

In traditional spectral inversion method, filtering progress is generally conducted by using band-pass wavelet or Ricker wavelet. Then the relative wave impedance is gotten by making −90 degree phase rotation of the reflectivity cube data (Zeng and Backus, 2005) [5] [6].

However, a type of wide-band Ricker wavelet (**Figure 2**) which composed by a series of Ricker wavelets with different band widths has been proposed by

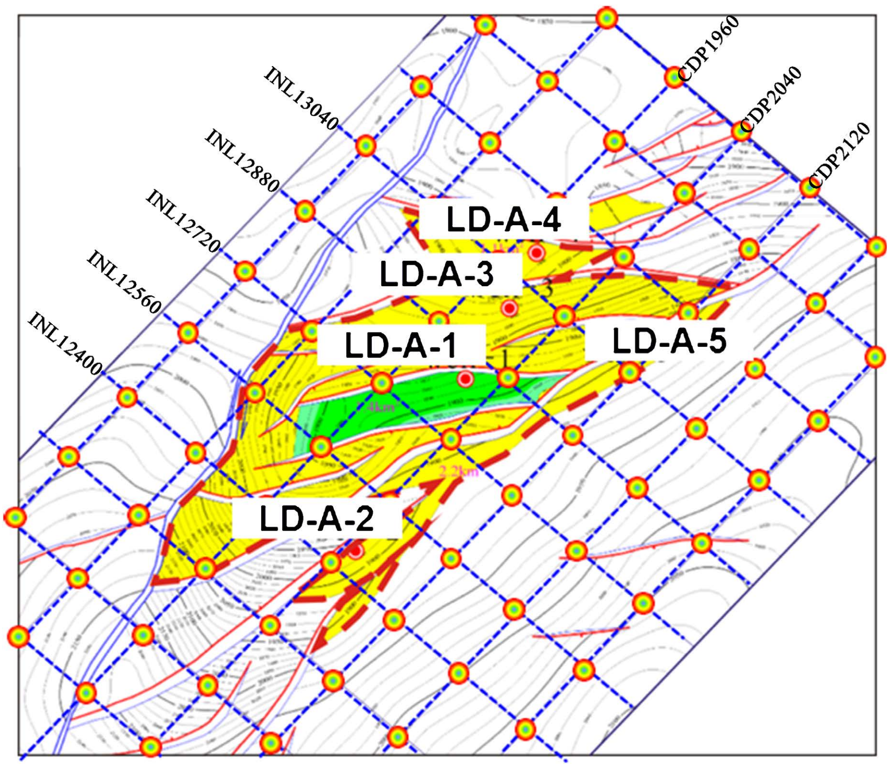

Figure 1. Shows a structural map of a fine interpreted oil-formation named H1 of LD-A structure.

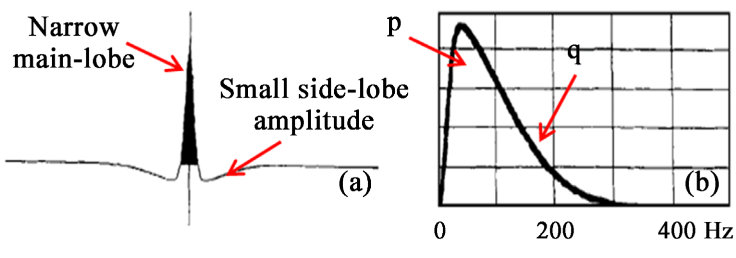

Figure 2. Shows wide-band Ricker wavelet (a) and the corresponding amplitude spectrum (b).

Portniaguine and Castagna (2004) [2]:

$$y(t)=\frac{1}{q-p}\int_{p}^{q}\left[1-2(\pi gt)^{2}\right]\mathrm{e}^{-(\pi gt)^{2}}\mathrm{d}g=\frac{1}{q-p}\left(q\mathrm{e}^{-(\pi qt)^{2}}-p\mathrm{e}^{-(\pi pt)^{2}}\right) \quad (1)$$

where g is a parameter which represents the dominant frequency of Ricker wavelet, p and q control the left and the right parts of the spectrum of the wide-band Ricker wavelet.

This wavelet is characterized by narrow main-lobe, small side-lobe amplitude and simple waveform. By adjusting the p and q values of Equation (1), we can get wavelets with different frequency bandwidth and different peak frequencies. The rate of descent speed of the high and low frequency can also be adjusted so as to meet kinds of application requirements

Structural constrained spectral inversion combined with wide-band Ricker wavelet filtering

In order to avoid extracting wavelet purposeless within the whole seismic work area, we propose a method named structural constrained spectral inversion which contains the following steps:

1) First, pay attention mainly on the potential reservoirs and make optimal selection of the drilled wells which hold representative feature of interesting structures.

2) Then, after making elaborate time-depth calibration, extract time-varying wavelets which will be used for removing from the seismic data within our target formation. Also, In order to avoid testing the wavelength repeatedly, we make use of the signal-to-noise ratio (SNR) relationship of the original seismic and the synthetic record in the wavelet extracting process (when the length of wavelets reaches a reasonable range, the SNR is high).

3) At last, use the structure representative wavelets in spectral inversion for obtaining inversion results. The spectral inversion algorithm of Puryear and Castagna (2008) [4] has been adopted here.

In order to make the filtering results have both wide-band and high signal-to-noise ratio. We have brought in the wide-band Ricker wavelet for filtering the reflectivity cube obtained by spectral inversion. Besides, in order to avoid filtering the cube purposeless, the filtering progress is also conducted under the constraint of our interesting structure and comprehensive analysis of the spectrums of raw seismic data, reflectivity cube and wide-band Ricker wavelet has been done.

In the following section we will take LD-A structure as an example to show the implement of our method.

The application of the method

LD-A structure locates in the northeast part of Bohai Bay. The upper section of the main oil-bearing stratum named Dongying formation of LD-A structure is characterized by fast lateral variation of reservoir thicknesses. Before our study, a total thickness of 61.5 m oil had been discovered by well-1. The seismic data of our target has a dominant frequency of about 30 Hz, and the P-wave velocity is about 3000 m/s. **Figure 3** shows profile of original seismic data across well-1 in time zone. The given figures represent the total thickness of pure reservoirs. However, the total thickness of each set of strata circled in **Figure 3** is less than $\lambda/8$. Thus, according to Widess model, the circled thin reservoirs of LD-A structure can't be identified.

According to **Figure 1**, it is clear that within LD-A structure well-1 which locates at the high part of effective trap is close to the centre of our interesting area (circled by discontinuous red line). After analysing the structure around, we find well-1 has the representative feature of our interesting area. Thus, we can make full use of the well to conduct our method.

Figure 4 shows the elaborate well-seismic calibration of well-1. H1 represents the interpreted horizon as shown in **Figure 1**. It can be seen that the correlation

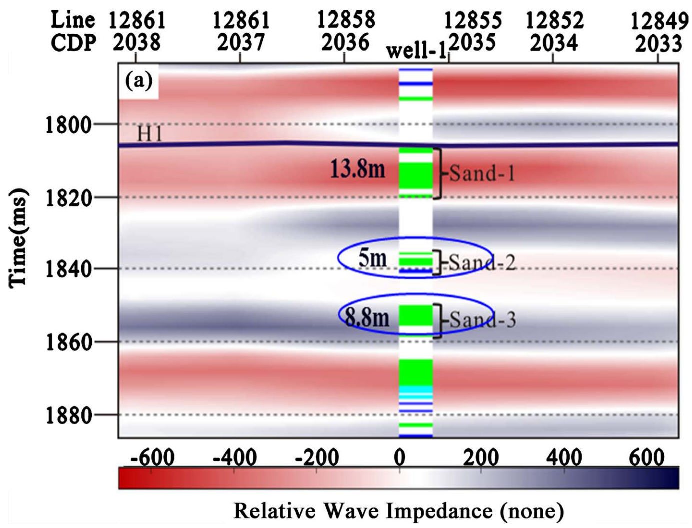

Figure 3. Shows profile of original seismic data (whose phase has been made a −90˚ rotation) across well-1 in time zone. The low impedance red events represent reservoirs.

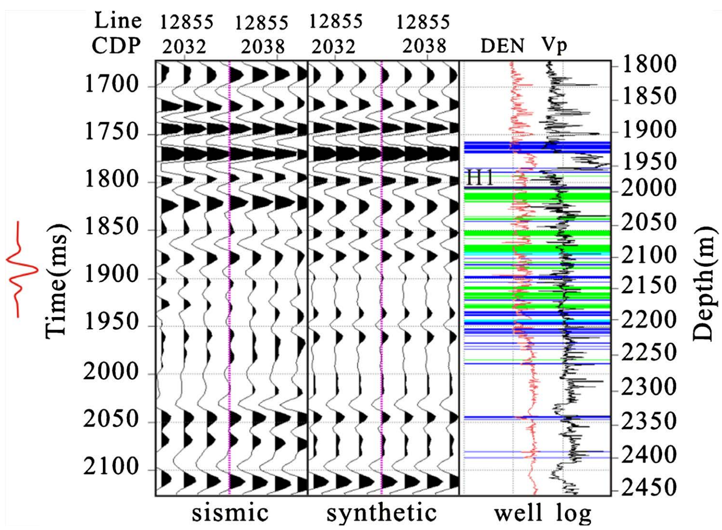

Figure 4. Shows the fine well-seismic calibration of well-1. H1 is the fine interpreted oil-formation as shown in **Figure 1**.

value is very high which helps with the precise location of reflecting interfaces. Figure 5(a) shows us three time-variant wavelets which will be used in the subsequent spectrum inversion.

During the extraction of wavelets (Figure 5(b)), the best-fit signal-to-noise ratio has been used to avoid repeated testing of wavelet length which is often done in traditional spectral inversion method. Figure 5(c) shows that when SNR is the highest the wavelength lasts about 120 ms.

Then, in order to get the wide-band reflectivity cube of the original seismic data, the extracted structural constrained time-varying wavelets will be used in spectrum inversion process given by Puryear and Castagna, 2008 [4].

In the next filtering step, the spectrum information of several high parts of the structural trap marked by dotted red line circle (as shown in Figure 1) has been considered. After detailed comparative study of the spectrum characteristics of the original seismic data, the reflectivity cube data and the wide-band Ricker wavelet, the wide-band filtering process has been finished. Figure 6(a) shows the wide-band Ricker wavelet filtering process, the black line indicates the spectrum of the reflectivity cube data, the red line indicates the spectrum of a desired wide-band Ricker wavelet, and the blue line represents the cut data. In Figure 6(b),

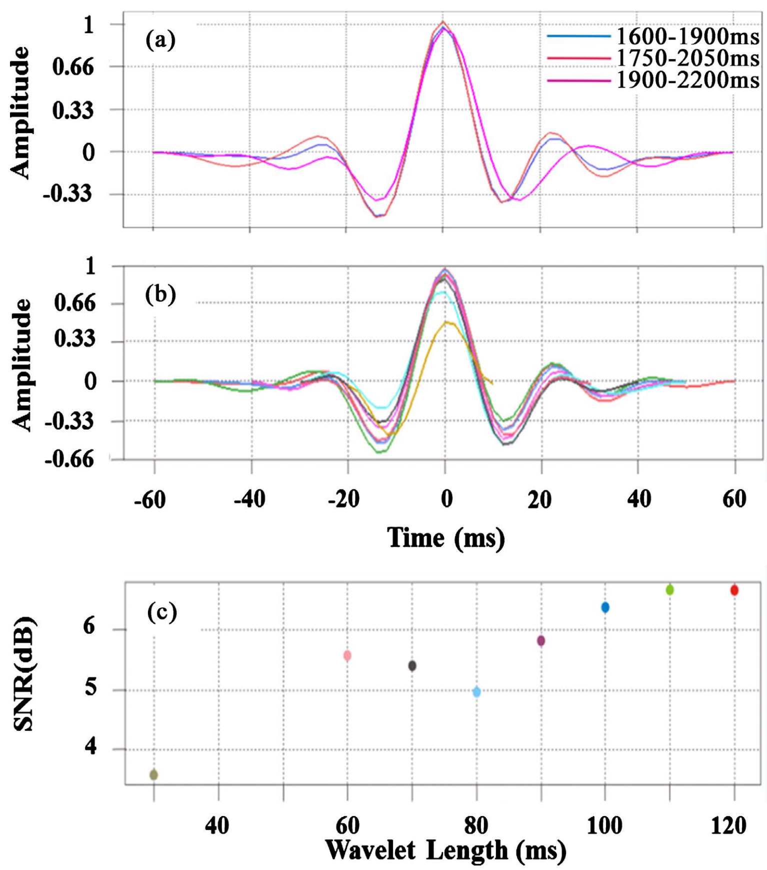

Figure 5. Shows the extracted time-variant wavelets. Each of the three colors indicates a wavelet extracted during a certain time range (a), the extracted eight wavelets with different wavelength (b) and their corresponding SNR (c).

the red line denotes the spectrum of the filtered result and the black line has the same meaning as in **Figure 6(a)**. **Figure 6(c)** shows the spectrum of original seismic data for comparison. It is clear that, by using our provided method, the low-frequency noise of the original seismic data around the zero part has been suppressed, and the frequency spectrum of the effective signal has been improved reasonably.

<u>The recognition of thin reservoirs</u>

After the above processing steps, in order to identify the thin reservoirs, **Figure 7** shows profiles of both the original seismic data (a) and the filtering result data (b) with a −90˚ phase rotation.

Apparently, both of the circled thin reservoirs have been distinguished much better in **Figure 7(b)** than in **Figure 7(a)**.

As seen in **Figure 8(b)**, we find that, just below the H1 horizon, there has a clear continuous event around the zone of well-3 which had not been drilled before we conducted the study. However, in the profile of the original seismic data the corresponding layer is broken and hardly to be identified (as shown in **Figure 8(a)**). The continuous event has been proved to be a thin reservoir by drilling well-3. **Figure 9** shows the minimum relative impedance properties of the

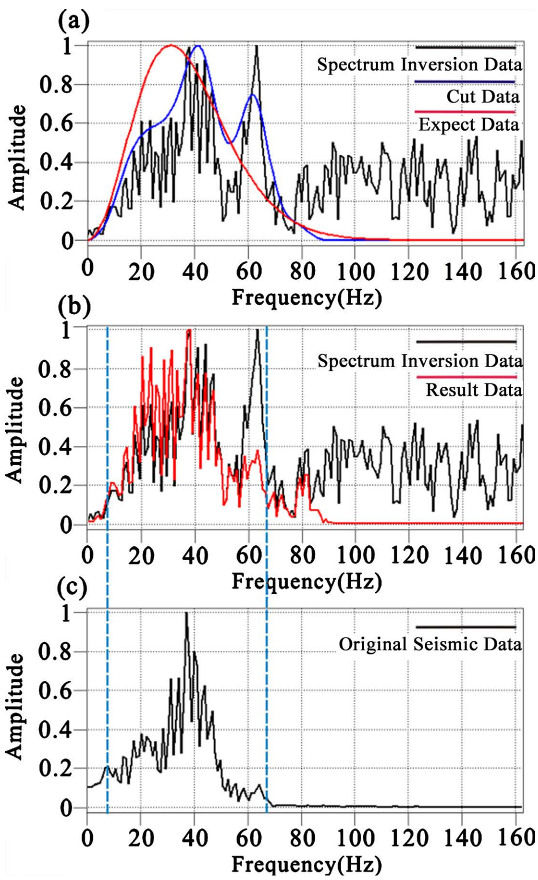

Figure 6. Shows the wide-band Ricker wavelet filtering process (a), the spectrum comparison of the reflectivity cube data and the filtered result data (b) and the spectrum of original seismic data (c).

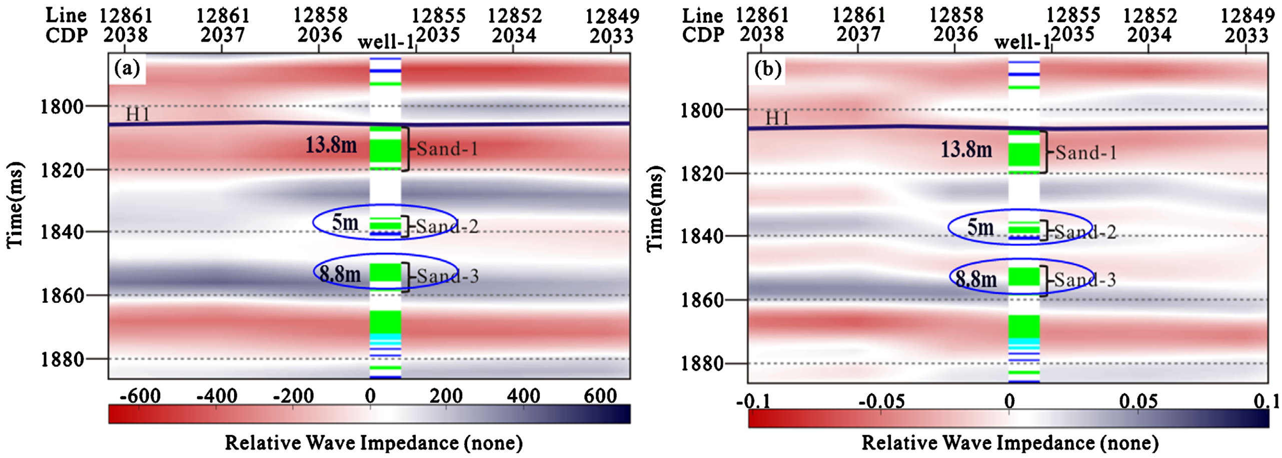

Figure 7. Shows the profiles of original seismic data (a) and new data (b) across well-1, the phases of both the data have been made a −90˚ rotation.

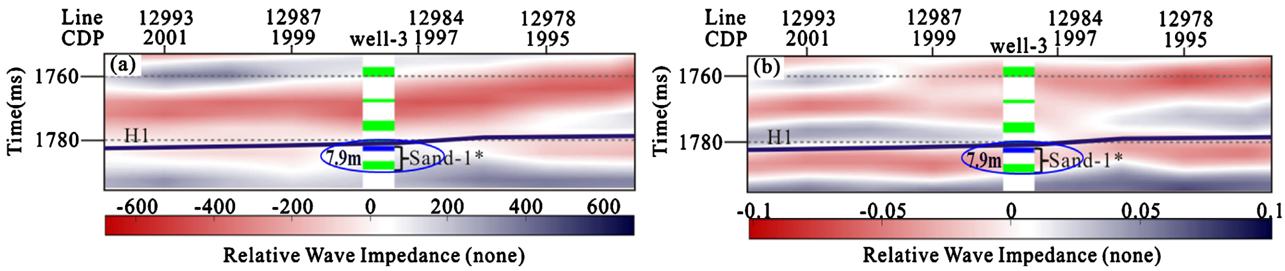

Figure 8. Shows the profiles of original seismic data (a) and new data (b) across well-3, the phases of both the data have been made a −90˚ rotation.

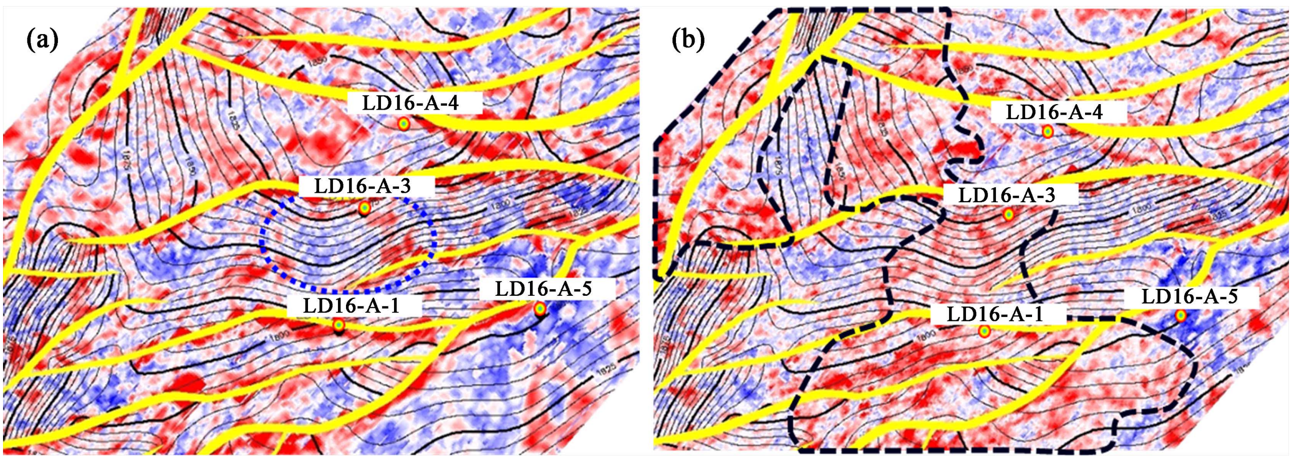

Figure 9. Shows the minimum relative impedance properties of the thin reservoir which bellows H1 based on original seismic data (a) and new data (b).

thin reservoir based on original seismic data (a) and new data (b). Also, with the application of this method (as shown in **Figure 10**), a thin sand layer named sand2 whose thickness is less than $\lambda/8$ in high oil yielding (Near 700 m^3/day) II-oil group of Es2 Formation has been identified accurately, which provides credible information for subsequent oil exploration and development.

In a word, by using our method on the original seismic data, it becomes easier

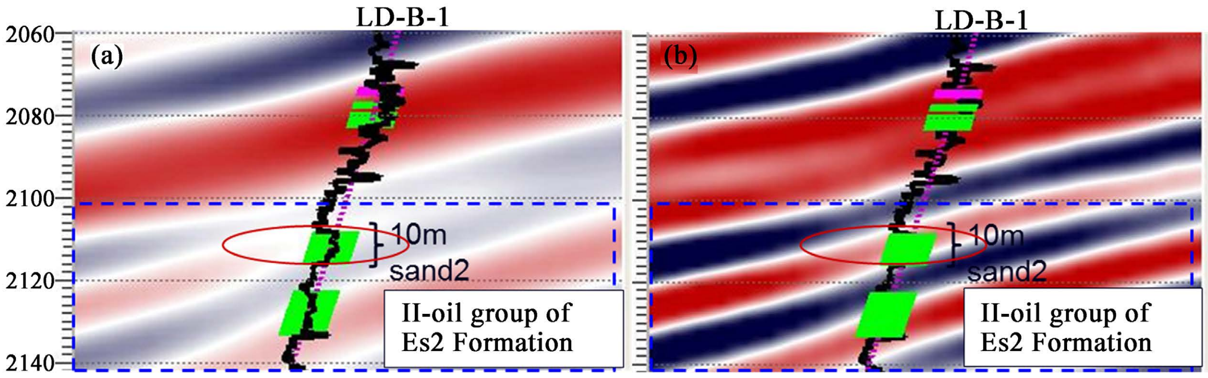

Figure 10. Shows The profiles of original seismic data (a) and new data (b) across LD-B-1, the phases of both the data have been made a −90˚ rotation.

and more accurate for us to track the thin sands. And the filtering result data can provide with credible information for subsequent oil exploration and development.

3. Conclusion

Based on the above studies, an effective and accurate thin reservoir prediction method which combines spectral inversion and wide-band Ricker wavelet filtering has been proposed. Under the constraint of our concerned structure, the gotten result makes the potential reservoirs have high resolution. LD-A structure has been taken as an example to show the implement of our method and the gotten results can help with the subsequent oil exploration and development.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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