Amplitude-Preserving and High Resolution Processing Method for Land Single-Point Seismic Data Acquisition

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Abstract. Comparison of single point acquisition seismic data on land with the seismic data collected by combined geophone, the original single shot has the characteristics of heavy noise and low resolution. It is necessary to effectively remove noise and improve resolution in order to meet the geological needs of thin sand body recognition. Using frequency division linear noise attenuation technology can effectively eliminate the influence of surface wave interference, fine denoising in multiple links, and improve the signal-to-noise ratio of data; near-surface Q-compensation and two-step surface consistent deconvolution are used to recover the effective signal energy. After stacking, the seismic frequency band is further broadened by spectral shaping based on global statistical wavelet. The bandwidth of seismic processing results reaches 6–90 Hz, the synthetic record of new drilling with this seismic data matches well. The combined application of many technologies has formed a high resolution processing method and technical process for single point acquisition seismic data, which can electively improve the imaging quality of seismic data.

Keywords: Single point acquisition · Seismic processing · Denoising · High resolution

J. Lin (Ed.): *Proceedings of the International Field Exploration and Development Conference 2019*, SSGG, pp. 1654–1662, 2020.
https://doi.org/10.1007/978-981-15-2485-1_149

1 Preface

Single point acquisition is to use a single geophone to receive seismic data in the receiving link. Using a single high sensitivity broadband geophone, drilling, wedge reinforcement, soil filling and compaction, sand bag sealing, the geophone coupling is ensured, and the receiving effect is better. In the past, combined well excitation and high frequency geophone combination reception were used. Because combined excitation and reception can suppress high frequency seismic signals, and high frequency geophone itself can suppress low frequency signals, resulting in the lack of low frequency and narrow seismic frequency band, which is not in line with the requirements of broadband excitation and reception. So in the high precision three-dimensional seismic acquisition, the method of single well small charge broadband excitation and single high sensitivity broadband geophone reception is used instead of the conventional three-dimensional seismic combination excitation and reception. At the same time, single-point acquisition technology also has the advantages of improving field construction efficiency, large dynamic range of data, high sensitivity, high fidelity of signal and low cost of acquisition [1–5].

FY oil layer is one of the main targets for petroleum exploration in the north of Songliao Basin, the reservoir is shallow lake delta distributary channel sand body, which has the characteristics of narrow transverse scale (200–800 m), thin single sand body thickness (2–5 m) and superimposed space. Accurate identification of river sand bodies by seismic data is a difficult problem in exploration. Seismic acquisition and processing is the key to how to obtain high fidelity and high resolution seismic data [6, 7].

2 Analysis of Original Single Shot Data Collected from Single Point of Terrestrial Facies

YL three-dimensional seismic work area is located in Sanzhao depression in the north of Songliao Basin. In order to obtain high-precision seismic data more economically, a single analog geophone at 10 Hz was used to acquire three-dimensional data, and at the same time, a smaller bin of 10 m * 20 m and a higher density of three-dimensional data were obtained. This acquisition method has many advantages, but it also has some shortcomings, such as low signal-to-noise ratio, serious surface wave interference and weak energy of high frequency signal. Figure 1 is the general single-shot recording data in and around the work area. We can see that the noise of the single-shot data in the near-path position is very heavy, and the energy of the surface wave is very strong. Relatively speaking, the effective signal energy in high frequency band is very weak. Through the analysis of the actual single-shot data in Yongle area, the frequency bandwidth of single-shot record in Fuyu reservoir of target formation is 6–30 Hz at −20 db. The adjacent Zhao35 three-dimensional work area adopted a 28 Hz combined geophone acquisition method in 2005. Its target formation is Fuyu reservoir with a frequency bandwidth of −20 dB and a frequency bandwidth of 6–40 Hz (Fig. 2). Therefore, the signal-to-noise ratio of the single-shot record of the single-point acquisition data in this area is low, especially the effective signal energy in the high

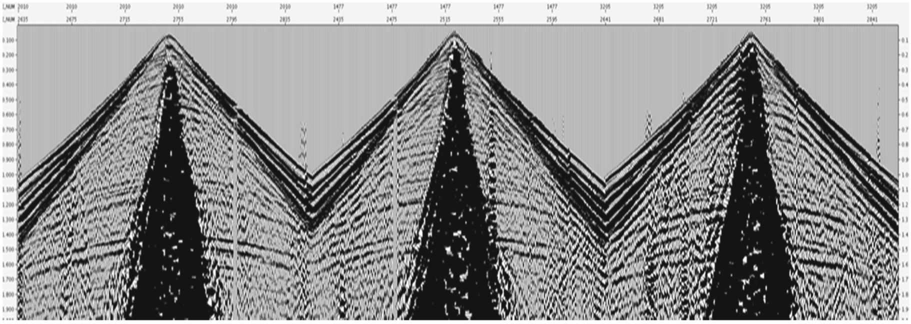

Fig. 1. Original single shot record of single point acquisition data in YL work area.

frequency band is very weak, so it is necessary to strengthen the research on the effective noise removal and the improvement of data resolution.

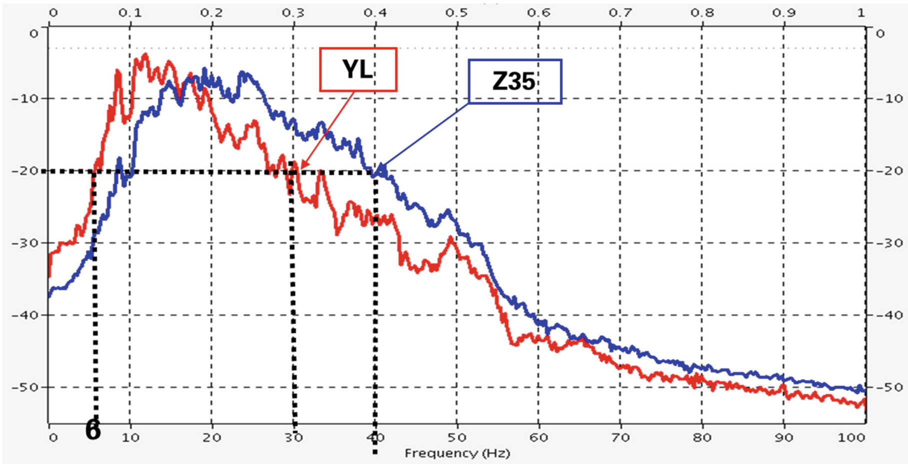

Fig. 2. Spectrum analysis and comparison map of YL workshop area and adjacent Z35 workshop area in target layer.

3 Analysis of Original Single Shot Data Collected from Single Point of Terrestrial Facies Fine Denoising to Improve Signal-to-Noise Ratio

The main interference waves in the work area are surface wave, refraction wave, high-energy interference and 50 Hz industrial electrical interference. It is necessary to select reasonable pre-stack denoising methods for different noises, so as to suppress the interference wave and improve the signal-to-noise ratio of data without damaging the effective wave. First, surface wave removal. At present, there are many kinds of surface wave suppression technologies, and the cross array surface wave attenuation technology has been widely applied. But Yongle Workshop used single point geophone to receive, which had wide surface wave frequency bandwidth and high apparent speed. It is difficult to separate surface wave from effective wave in F-Kx-Ky domain. The surface wave interference of single point geophone data can not be effectively eliminated by using this technique. Conventional subtractive surface wave suppression technology is based on the difference in frequency between surface wave and effective wave, surface wave interference is extracted from raw data, then the surface wave interference is subtracted from the original data to suppress surface waves. Experiments show that the subtraction method can not effectively remove surface wave interference. According to the characteristics of the surface wave of a single geophone, the frequency division linear noise attenuation (LNS) technology is selected to eliminate the surface wave interference effectively through various methods of experiment and effect comparison. The basic idea of this technology is to separate and extract the surface wave interference step by step according to the frequency and linear velocity characteristics of surface wave. The concrete realization process is as follows: First, through high-pass filtering and linear velocity analysis, it is determined that the frequency of surface wave in Yongle work area is between 12 and 18 Hz, and the linear velocity of surface wave is about five orders, and there are some differences in the frequency of surface wave with different velocities (Table 1); The second step is to establish the first-order surface wave model. The linear velocity of the first order surface wave (surface wave 1) is used for linear NMO correction of single gun records. The first order surface wave is flattened, while the other order surface wave and effective wave which are higher than the first order surface wave speed are not enough after linear NMO correction due to their low velocity, and the coaxial downward bending occurs. The adjacent three records are partially superimposed. Only the first-order surface wave can be superposed in the same phase because it is flattened, and the energy of the superposed surface wave can be strengthened. The other fourth-order surface wave and effective wave can not be superposed in the same phase, and the energy of the superposed surface wave can be weakened each other. Thus, the first-order surface wave model can be obtained by superposition processing. The third step is to remove the first-order surface wave and use the linear velocity of the first-order surface wave as the inverse linear NMO correction, then subtract the first-order surface wave from the original single-shot record to get the single-shot record. In the fourth step, the other fourth-order surface waves are extracted by the above two processes in turn, so that the influence of surface wave interference can be effectively removed and the signal-to-noise ratio of data can be improved by means of step-by-step separation, extraction and removal. Figure 3 shows the single-shot and noise records before and after surface wave removal by frequency division LNS technology. The single-shot after noise removal can hardly see the surface wave interference, and the effective signal can not be seen in the noise records removed. LNS surface wave interference removal technology can effectively remove surface wave interference while protecting the effective signal to the maximum extent. For many other types of noise, it must also be carefully removed. For example, the frequent high voltage line interference, i.e. 50 Hz industrial electrical interference, which reduces the signal-to-noise ratio of the original data, and uses subtraction single-frequency wave suppression technology to remove it. There is strong refraction interference in some single guns in high hill area. According to the characteristics of strong linear relation of refraction wave, relatively stable apparent velocity and low apparent velocity of effective wave, F-X correlation noise attenuation technology is used to suppress refraction wave interference. Noise removal runs through every processing step. According to the different characteristics of noise in different processing links, the idea of frequency division, time division, region division, classification, step division and zoning is adopted to fine denoising, so as to gradually improve the signal-to-noise ratio of data [8].

Table 1. Various types of surface wave parameter table.

Surface wave	Surface wave 1	Surface wave 2	Surface wave 3	Surface wave 4	Surface wave 5
Velocity (m/s)	200	250	350	460	790
Frequency (Hz)	12	12	12	18	16

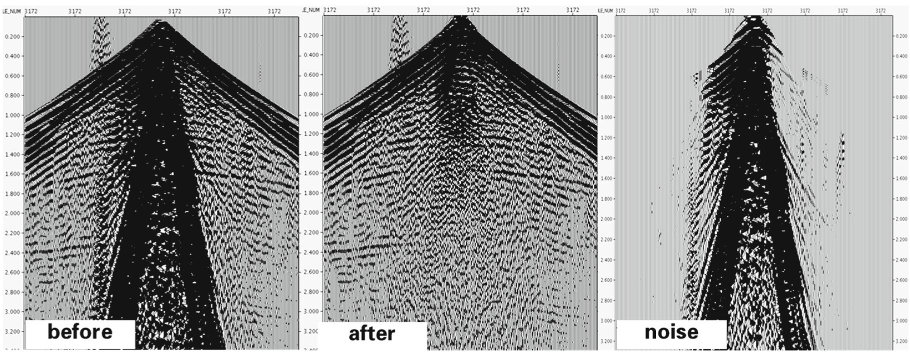

Fig. 3. Single gun and noise recording before and after surface wave removal by LNS technology.

4 Improving Resolution Processing

The higher the resolution of seismic data is, the stronger the ability to reveal the stratigraphic structure and reflect the spatial variation of lithologic assemblages is. Especially for the prediction of thin and small distributary channel sand bodies in continental facies, the relative high resolution data means that the prediction accuracy may be higher. Over the years, Daqing Oilfield has been devoting itself to the study of thin continental reservoir prediction, forming a series of effective techniques for processing and interpretation, and taking the effective improvement of seismic resolution as the primary task [9]. How to effectively improve the vertical resolution of seismic data needs to be implemented in all aspects of seismic processing and gradually realized. Finally, the data of this work area show that the main effective technologies include pre-stack high resolution technologies such as surface Q compensation processing for near-surface absorption, two-step surface consistency deconvolution processing, and post-stack spectral shaping based on global statistical wavelet.

Near-surface deposits are loose and have a strong absorption effect on seismic signal energy, especially for high-frequency components. Surface Q compensation technology is the combination of surface travel time and seismic data using micrologdata. The relative Q value is calculated by spectral ratio method, and then compensated by efficient and steady Q compensation algorithm, which can compensate the near-surface absorption and attenuation of seismic data. Deconvolution is the most critical step in seismic data processing. Only by deconvolution can we effectively eliminate the influence of seismic wavelet, obtain reflection coefficient, improve the resolution of seismic data, correctly reflect the information of underground reservoirs, and provide reliable basic data for oil and gas exploration. In order to eliminate the influence of surface inconsistency on seismic wavelet, enhance the lateral stability of seismic wavelet and restore the reflection coefficient of underground stratum, the surface consistency deconvolution technology is further adopted on the basis of surface Q compensation to make seismic waves consistent in horizontal direction, compress wavelet in vertical direction and improve resolution. By comparing and analyzing the results of predicted step size scanning, it is considered that the predicted step size of 1 ms is a relatively suitable deconvolution parameter for surface consistent deconvolution in this area. After surface Q compensation and surface consistent deconvolution in artillery detection domain, the effective frequency of the target layer of the profile has been significantly increased. The main frequency of the target layer reaches 35 Hz and the bandwidth reaches 6–65 Hz, and the profile is in good agreement with the synthetic record.

In order to improve the accuracy of thin reservoir prediction, it is necessary to widen the frequency band and improve the resolution of data in post-stack processing. A large number of experiments have been carried out and the spectral shaping technique based on global statistical wavelet has been optimized finally. The basic ideas of this technology are as follows: Firstly, the energy of medium and high frequency end is increased by Q compensation. Secondly, in the superimposed section after Q value compensation, the spectrum analysis is carried out for the target layer, and all the spectrum is superimposed and smoothed. The spectrum representing the whole work area is obtained. Thirdly, the energy envelope of the amplitude spectrum before and after Q compensation is the desired output, and the expected output spectrum is obtained. The phase spectrum is zero and does not change the phase relationship of the data. Thus, the spectral shaping operator based on global statistics is obtained. Fourthly, the spectral shaping operator of global statistics is applied to the data, so that the low-frequency end of the data is broadened, and the Q-value compensation is retained to enhance the mid-high frequency energy, and the broadband high-resolution data is obtained. With this technology, the vertical resolution is greatly improved, the main frequency of the earthquake is increased from 35 Hz to 50 Hz, and the bandwidth is further broadened to 6–90 Hz. The target layer of the result profile is in good agreement with the synthetic record of 50 Hz (Fig. 4).

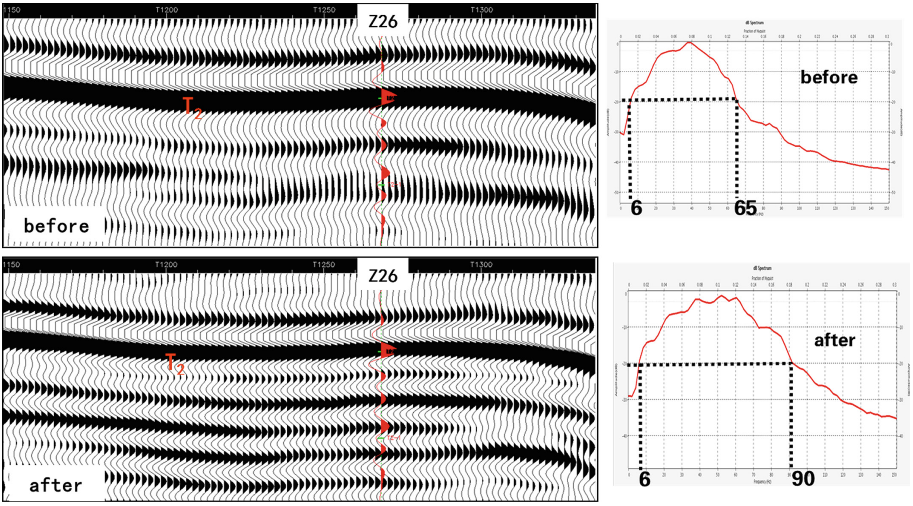

Fig. 4. Seismic profile and spectrum contrast analysis map before and after spectrum shaping based on global statistical wavelet.

5 Application Effect Analysis

Through the above processing, the vertical resolution of seismic data basically meets the geological needs, and seismic attributes can also reflect the sedimentary law and sand body distribution characteristics, and there is no abnormal phenomenon of gathering footprints and energy. The breakpoints and sections and the imaging of fracture system are clear of coherence cube attributes. The quality of seismic processing results is preliminarily evaluated by these effective means, which meets the requirements of energy consistency and effectiveness [10]. The processing results have been successfully applied to drilling several exploration wells in this area. Taking Y63 well of one exploration well as an example, this well is a posterior well. Using the processing results of single point data, it is predicted that Y63 well has four sets of channel sandstone bodies in the target formation. The actual drilling results show that four sets of oil-bearing channel sandstone have been drilled in the target formation, and the thickness of sandstone body is 3.2 m, 3 m, 7.4 m and 4.6 m from top to bottom. The well's synthetic seismogram (50 Hz Rick wavelet) matches well with the seismic profile (Fig. 5). Sandstone is calibrated in the middle and lower part of the peak, and the seismic response characteristics of sandstone are clear. Therefore, the ability of seismic prediction of sand body is strong, which further verifies the reliability of the single-point acquisition data processing technology in this area.

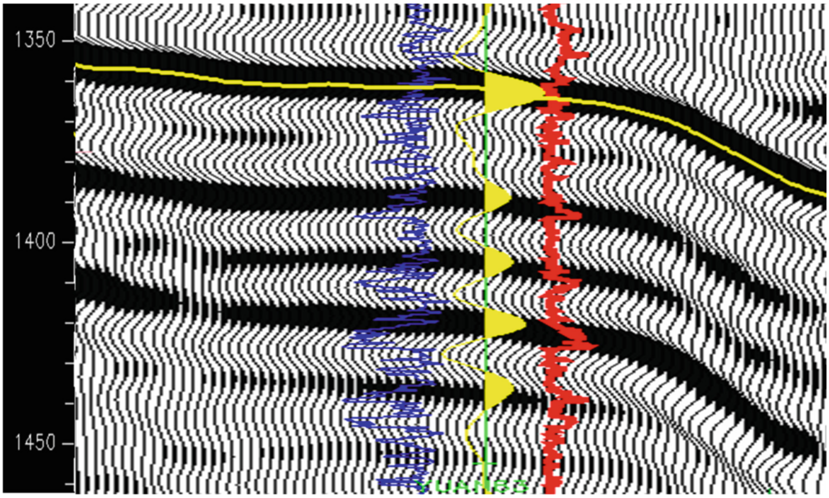

Fig. 5. Composite record analysis diagram of Y63 well in YL area back well (arrow location is drilling sandstone location).

6 Conclusion

There are many types of noise in land single-point seismic data acquisition. The signal-to-noise ratio of data is improved by denoising, which runs through the whole processing process. For different types of noise, corresponding removal methods can be formulated according to the characteristics of noise itself. Frequency division linear noise attenuation technology can remove complex surface waves. Near-surface Q-compensation and surface-consistent deconvolution can restore high-frequency signal capability and improve seismic resolution in pre-stack processing. Spectral shaping based on global statistical wavelet can greatly broaden the effective signal bandwidth in post-stack extension. The application effect of the final result of seismic processing in exploration can be confirmed, and the processing method for single point acquisition data is effective.

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