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The Seismic Acquisition Method Researching for the Complex Mountainous Terrain in YXL Area Qaidam Basin

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Abstract

YXL area is the concentration area of exploration activity with classic complicate surface feature in Qaidam Basin. So, its interference wave is development and the seismic data is in low signal-to-noise ratio (SNR) in the area. Through multiple seismic exploration collecting means, Acquisition techniques has obtained great breakthrough, and array technique has showed great affection. The geological tasks and seismic exploration difficulties of target area is aimed in the paper. The remained problems in the past seismic exploration is dissected, studying the noise interference feature and the effects for the array noise attenuation. And the positive roles of the stack response for the noise attenuation is discussed and to supply the high quality and the high precision data for the seismic in this area.

Key words: Shot-receiving array; Stack array response; Geometry; Direction effect; Array weighted average effect; Signal-to-noise ratio

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INTRODUCTION

YXL area is located in the west of Qaidam Basin. The surface wave, refracted wave and other linear interference wave of seismic acquisition data are more developed because of its particular geographical and earth surface condition. Since last century 80 s, Based on the interference wave characteristics and the earth surface condition (Desert, sand land, sand dunes, saline, grass land and swamp), a suit effectual combined seismic method had been concluded around the YXL area where is flat relatively. It obtained distinguished exploration effective for attenuation the interference wave and improving the signal-to-noise ratio.

With the knowledge of the geologic, the seismic exploration area has headed to the complex mountainous region from flat surface. The structural belt has the exploration value potentially in YXL area. The belt belongs to typical complex mountainous (Figure 1). It has surface weathering and denuded seriously and the developed gully. Configuration relative fall reaches 50-400 ms. The parts of the stratum of Neogene system(N) is crop out. The lithological character is grey-yellow and light grey sand shale inter-bed aridly and loosely. In the past, the connection with great building difficulty of seismic exploration, the seismic data qualities were low relatively, which made structural detail not clear. So it affects the progress of the seismic exploration seriously.

By now, the seismic exploration technique for the complex mountainous region has experienced following four stages:

The first stage (years of 1996-2002): Researching of conventional 2D seismic exploration . The shot-pattern is the mid-deep well with the less than 5 wells shooting parameters. The receiving parameters are “X” type assemblages with 48 geophones are used. The coverage is 120. Although trying to medium-deep well assemble shooting, we use the horizontal widen assemblage for attenuation noise and improving the qualities of the data. The method had not got the effect what we want.

The second stage (years of 2003-2007): High density acquisition and wide-line (2D) acquisition. The short group interval (10 m) and the vertical line geophone array with the horizontal widen assemblage (L_y = 115 m) was used in the high density acquisition. Trying to high density seismic acquisition and to attenuate the noise for improving the signal-to-noise ratio. But it had not obtained expectance effect. Broadened line (2D) observation geometries are 2 lines and 2 shots. Receiving geometries are twenty geophones arrays and the assemblage figures looks like a square or equality sign. The source geometries are the shot-pattern is the mid-deep well (15-35 m) with the less than 5wells. The fold is 480. The qualities got much improvement because of the more coverage. Structural figures are practicable essentially and got the breakthrough in the seismic exploration, but it is still not meet the needs for the data interpretation.

The third stage (year of 2010): 2D seismic acquisition with the wide-line and large group. The acquisition geometry is 3 lines and 3 shots. Receiving parameter is forty geophones with "+" type. The more wells (8 m) pattern is used as the source parameter. Patterns interval is L_x = 30 m. Fold is 810. The large arrays was used to attenuate the interference wave for improving the qualities of the seismic cross section. From initially seismic data, mountainous reflection group got more rich and faults shows are more clearly in mountainous.

The fourth stage (years of 2011-2012):3D seismic acquisition. The distance between the geophone and well must be over 4m and 6m, and lay out them widely as possible as we can according to the design. The geophone parameter is types "Y" with 30 geophones. Source parameter is designed with the shallow wells and multiple shot-points. Patterns interval is L_x = 48 m. Coverage is 312. From the feature of mountainous 3D seismic, Using the patch and high coverage can attenuate the noise and improve the data signal-to-noise ratio greatly.

From seismic cross-section, reflection signature above basement is obviously, the layers show clearly and continuance enhancement. The method increase the interpretation accuracy of the geological structure, but it is still insufficient in detail.

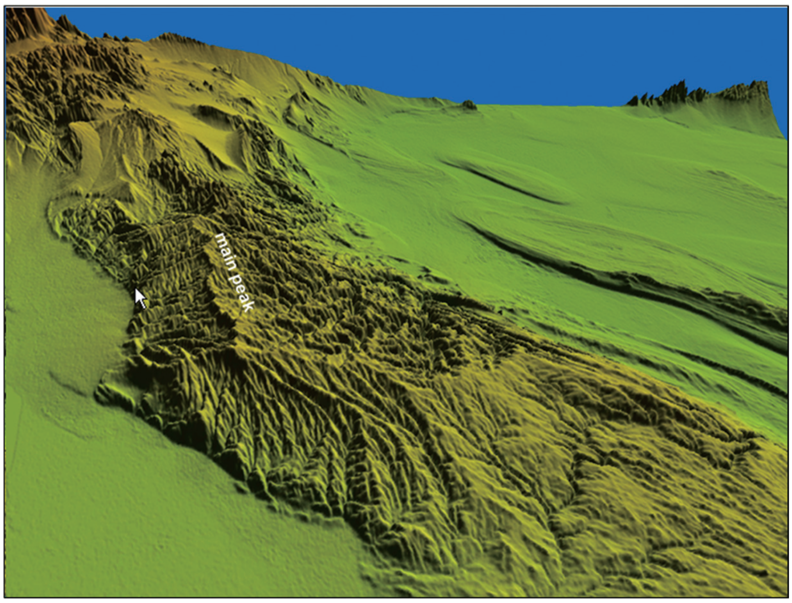


Figure 1
Configuration and Geomorphologic Characteristic YXL Area

Through the decades researching, the major breakthrough for the seismic acquisition technology in complex mountainous had been obtained. But the mountainous seismic acquisition methods still need to conclusion constantly, studying and research. The previous seismic acquisition technique and its effect are analyzed in this paper. Focusing on seismic array and geometry design is for noise suppression and improving the signal-noise ratio. And the goal is to provide some suggestions for the acquisition design of 3D seismic exploration around YXL area lately.

1. INTERFERENCE WAVE AND ATTENUATION NOISE PATTERN CHARACTERISTICS

Example the 3D seismic records in YXL area for analysis the spectrum feature (Figure 2 and Figure 3). Linear interference waves (the surface wave, refraction etc.) were strong and the range is wide to the seismic records at the flat region., Due to the specific surface condition, the surface wave, refraction wave energy is weak, wave dispersion, continuities is weak in seismic records of mountainous. The inhomogeneities of the surface medium caused the side swipe, random interference wave (the phase change without law) developed relatively. The surface wave is characterized by low speed, low frequency. The apparent velocity is 280~1300 m/s, basic frequency is 5~15 Hz, apparent wavelength is 18~260 m; apparent velocity of refraction wave is 2100~2400 m/s, basic frequency is 8~12 Hz, apparent wavelength is 20~30 m; random interference has no propagation direction and the basic frequency is 5~20 Hz.

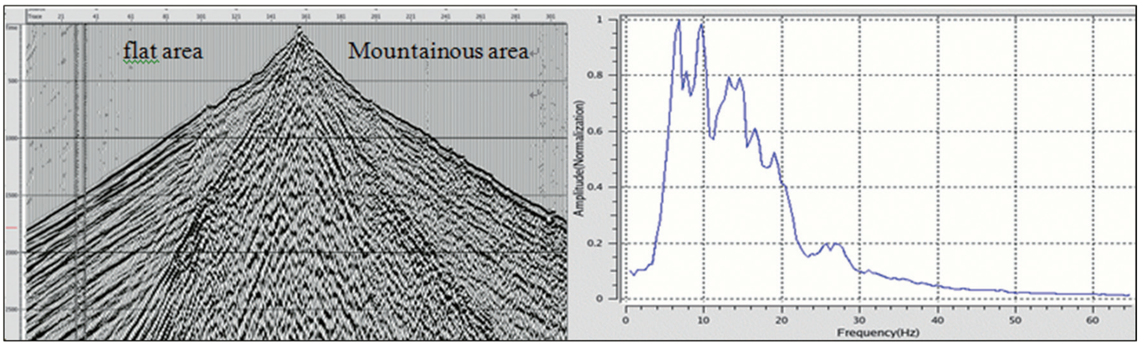


Figure 2
The Original Record and the Spectrum of 3D Seismic in DWS Field (Piedmont)

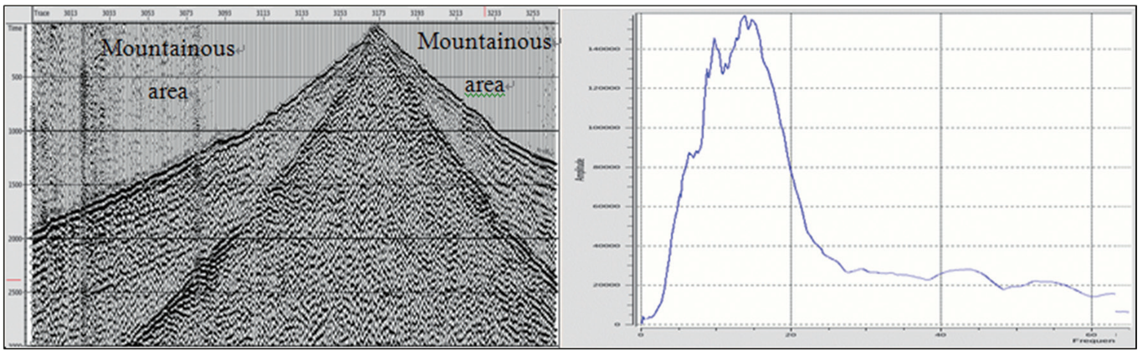


Figure 3
The Original Record and the Spectrum 3D Seismic in YSHS Field (Mountainous Area)

The method of 3D seismic acquisition with the " Y " type receiving pattern. array length: L_x = 24 m, L_y = 32 m; Shooting pattern: the shallow wells(8 m) with multiple shot-point was used in the flat area, array length: L_x = 60 m, and the shallow wells (less than 9 wells) shot-point was used in mountainous area. array length: L_x = 48 m. The details of Seismic pattern to see Figure 4 (leave out).

Selection linear interference wave as the apparent velocity(RMS)of 800, 2000 m/s. At first analysis the array response of shot-point and geophone-point with the 0^o direction (receiving).From frequency domain noise reduction characteristics, for the 10 Hz frequency interference wave, the 16-32 dB, 8-16 dB interference wave noise to be attenuated by the pattern(Figure 5). From the wave-number domain noise reduction characteristics, selection interference wave of the apparent wavelength as 40 m, 120 m, the 24-32 dB, 0-8 dB interference wave noise to be attenuated by the pattern. The same method is used to analyse pattern noise suppression characteristic of 90^o direction, but no details in here.

For seismic arrays, the pattern noise suppression has the strong directivity. The lower interference wave speed and the shorter wavelength, the better to the noise attenuation for the patterns[1].

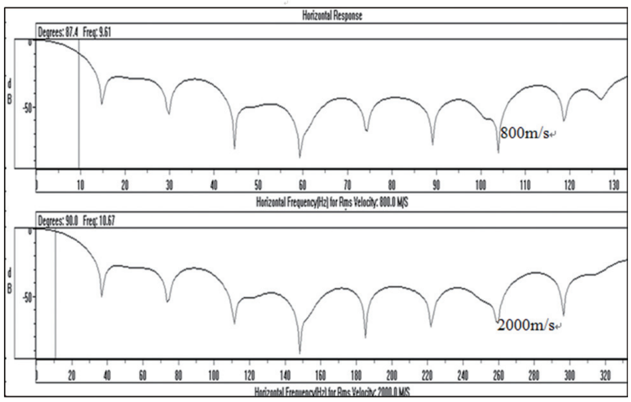


Figure 5
Frequency Domain-Noise Reduction Characteristic of the Shot Point and the Geophone Point Patterns

For 3D seismic exploration, the distribution of CMP bin inner azimuth relates closely to the noise suppressions characteristics of the geophone and shot patterns. Each azimuth represent a source-receiver pair (SR), the projection of the shot and geophone point to be done in its direction, The pattern interval and the array interval determines the noise suppression characteristics of the patterns in its direction. The pattern noise suppression properties in the CMP bin with all direction to be weighted average. The weighted value represents the bin combination average response[2]. If the acquisition footprint of the geometry is smaller, the minimal differences for each distribution of the azimuth inner bin and the noise suppression characteristics of each bin are also quite stable.

The following is 3D seismic acquisition geometry, observation type: 24 (Lines) 4 (Shots) 312 (Traces) orthogonal, coverage: 312, receiving number: 7488, swath rolling distance: 2 receiving lines.

From the above distribution of the geometry azimuth (Figure 6), 210 CMP bins are selected in a receiving line direction (full coverage zone). When the interference wave apparent velocity is 1300 m/s, the frequency is the range of 5-45 Hz. The noises below 18 Hz the frequency be attenuated as the normalized amplitude value (A) be decreased 0.1 (Figure 7) by the patterns of the shot-receiving (Figure 4) in each CMP bin.

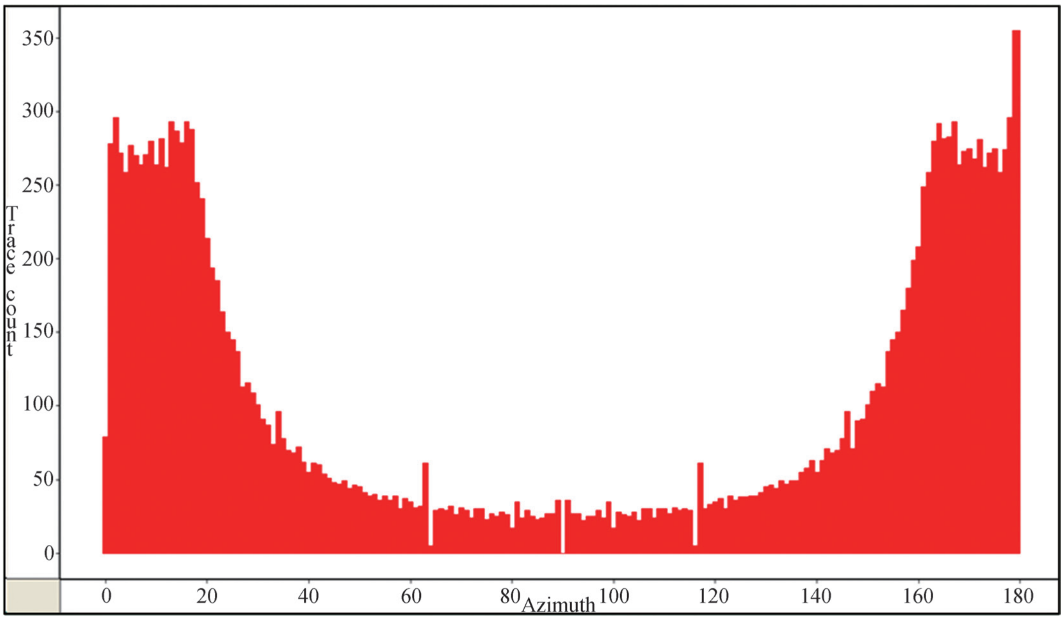


Figure 6
3D Seismic Geometry Azimuth Distribution

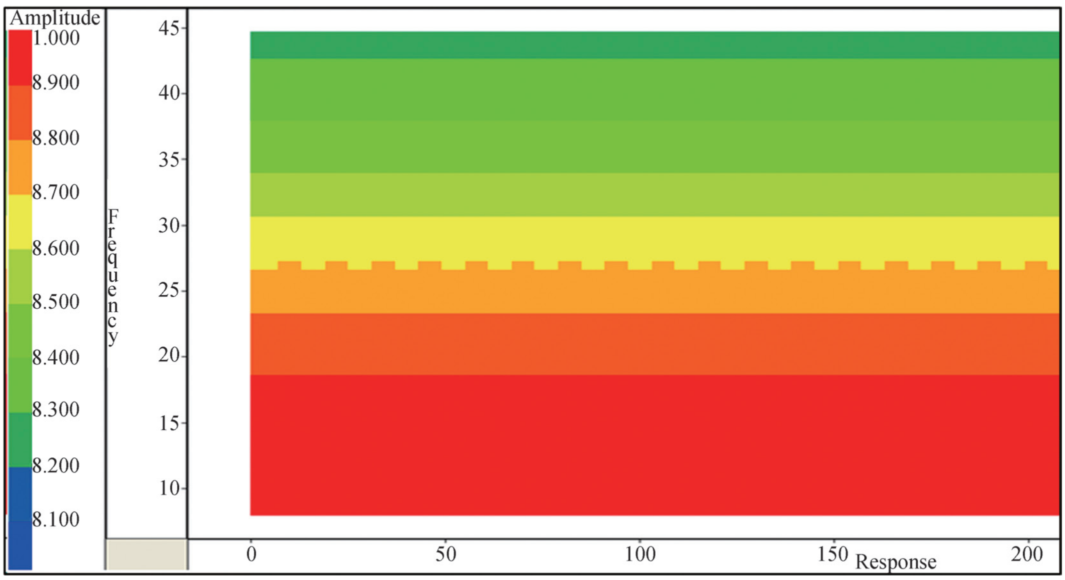


Figure 7
3D Geometry- Noise Reduction Characteristic of the Shot Point and the Geophone Point Patterns Inner CMP Bin

The stack response of 3D geometry to be obtained based on the distribution of the offsets inner CMP bins. But it's without the relative of the azimuth distribution. The regular offset distribution suppress the linear interference wave better than random interference wave [3]. The higher coverage, an approximately regular offset distribution inner each CMP bin, results the better stack response. As above geometry design, choosing any CMP bin is in full coverage area. The interference wave wavelength minimum 20 m, interference wave apparent velocity is also 1300 m/s. From stack response characteristics, the linear interference wave of the frequency between 5-45 Hz, the noises were attenuated 30 dB on average (Figure 8).

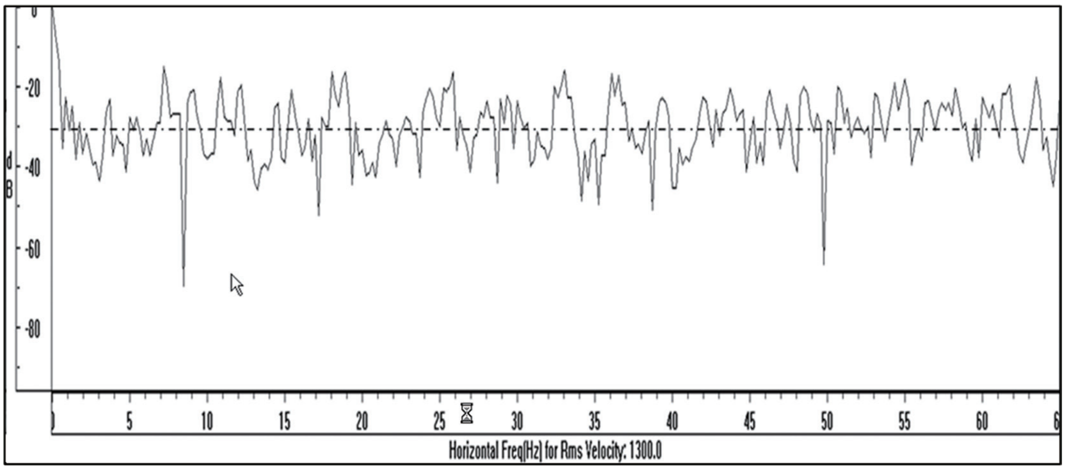


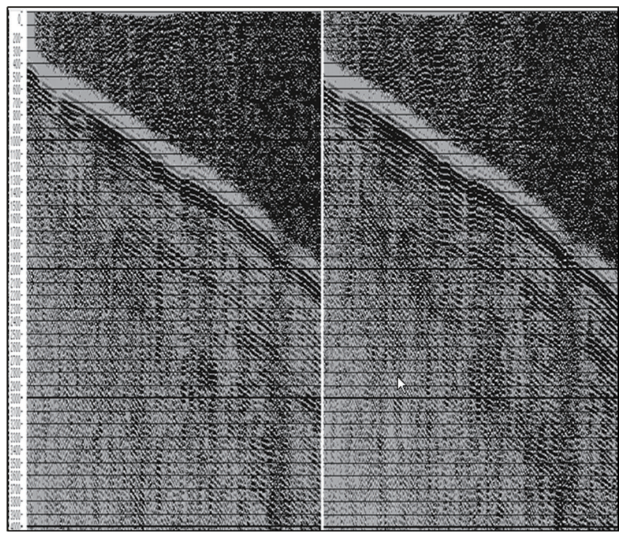
Figure 8
The Attenuating Characteristics of the Stack Array Inner CMP Bin

The above analysis of the characteristics of the array attenuating is the noise. The interference (noise) of the high frequency (15~45 Hz) was attenuated differently by the shot-geophone patterns. But it is limited for attenuating the mail frequency between (5~15 Hz). The interference wave in all frequency (0-65 Hz) were attenuated averagely. So the efficiency of noise suppression is improved quite quickly.

3. ACQUISITION TECHNOLOGY AND ITS EFFECT

3.1 Deep Well Shooting Techniques

The conditions of the shooting and receiving are badly in YXL mountainous area. Because of the surface weathering and denuded seriously, the lithological character of near-surface layer are dry and loose. By the depth of the shooting was changed to ensure the seismic wave energy transfer downward. The shooting depth in general 20-54 m that is shooting in sub-weathering layer (velocity 1200~1600 m/s), and injecting water into the wells. From the test seismic record (Figure 9), the depth of the shooting affect weakly to the variation of the signal-to-noise ratio and the frequency spectrum. From the data of near surface (up-hole survey), the zone of the low velocity layer (LVL) is very thick, the thickness reaches 70-130 m when the velocity of the sub-weathering is 1800 m/s. From data of the near surface formation (tomography model) (Figure 10), the bottom interface is smooth when the velocity is 2300 m/s, and the thickness is 100-500 m.



(a) (b)

Figure 9
The Original Seismic Record in YSHS Field
(a) Shallow Wells Pattern (4 wells × 18 m); (b) Deep Wells Pattern (4 wells × 36 m)

Therefore, the seismic wave energy is absorbed and attenuated serious greatly because of the thick low velocity layer in YXL mountainous area. Formerly, the lithological character of the middle and deep wells shooting was changed weakly compare with shallow wells shooting because of the all explosive were done in the low velocity layer actually. Under the primes of the shooting energies and cost consideration, the patterns of shallow wells (5-8 m)is reasonable better.

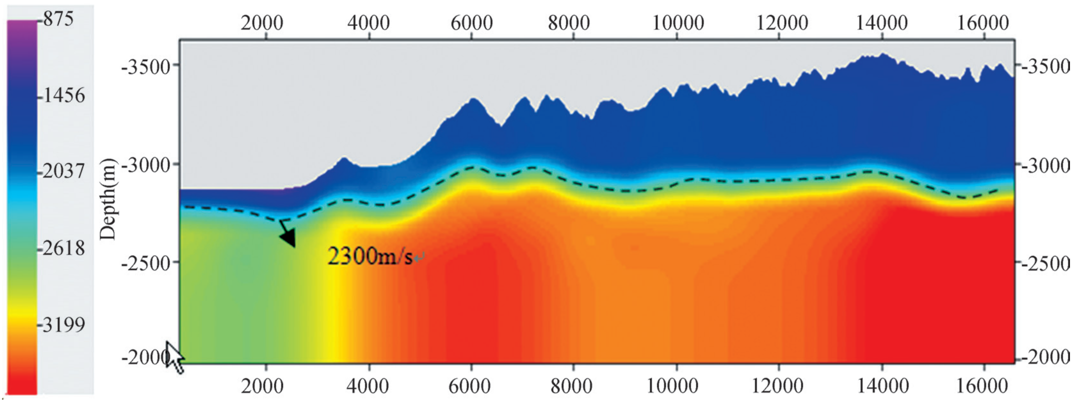


Figure 10
3D Seismic near Surface Tomography Model YSHS Field

3.2 The Technology of the Indoor Arrays Implement for the High Density Seismic Sampling

2D seismic acquisition of the high density, shooting factor is single well with 26 m deep, receive interval is 10 m, and with the multiple geophones lay out vertical to the line. The array interval L_y = 115 m, L_x = 0 m, element interval δ_x = 0 m, δ_y = 5 m, coverage is 800. Using seismic data processing (arrays implement method) for noise suppression and attenuation is for improving the signal-to-noise ratio of the seismic data.

From the analysis of the rose diagram for array suppressing noise, and the interference wave of the main frequency range (5~20 Hz), the noise is attenuated 8-56 dB with the patterns vertical to the receiving line, noise attenuation better. But it is almost no any attenuation parallel to the line. The field linear geophone pattern for attenuated the surface waves and refractions weakly.

From the seismic section effect (Figure 11), there is not the clear character of reflection group in mountainous area. And the fault location, structure outline is also not clear. It could not satisfy the needs for the oil and gas exploration and development. So the method does not achieve the desired effect in fact. In the noise suppression, it states that the field seismic patterns are much more important than the indoor array implement.

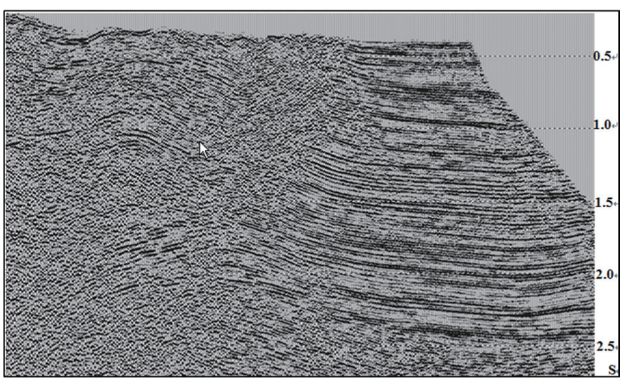


Figure 11
High Density Seismic Section in YQZ Field

3.3 The Technology of Array Suppressing Noise

The technology of the noise suppression by the seismic pattern can be traced back to the last century 80's in Qaidam Basin. Under the condition of very low coverage, the large-area pattern of the shooting (22 wells × 5 m deep, array length L_x = 88 m, L_y = 16 m) and receiving are used (Geophone array: 48 geophones, array length Lx=85 m, L_y = 15 m), and the interference noise is attenuated well in fact. So the quality of seismic data is improved, with the upgrading of the equipment for the seismic acquisition and the channel expansion for the seismic acquisition. The stack array of the high-fold was satisfied and the signal-to-noise ratio of the seismic data is also improved. The design of the geometry is emphasized for the seismic acquisition in complex mountainous YXL area, from the conventional 2D seismic acquisition to the wide line: 2 lines of 2 shots, 3 lines 3 shots (Figure 12), the coverage is increased to 120, 480, 810 in order. But there still are the shortages that can't be overcame for the designs of the wide line 2D geometry, the offset is repeated in CMP bin. So that the effective of the coverage is reduced, it is just 1/2, 1/3 actually, and affects the array effect of the horizontal stacking.

Although there are the deficiencies for the 2D seismic wide-line geometry design, the qualities of the seismic sections are improved with the acquisition technology implemented, and the 3D seismic exploration can be followed latterly. It is demonstrated that noise suppression and the signal-to-noise ratio are improved by the large array+ high coverage. On the base of the geometry design for the 2D wide-lines, the 3D geometry designs are optimized and the qualities of the data are optimized greatly (Figures 13, 14).

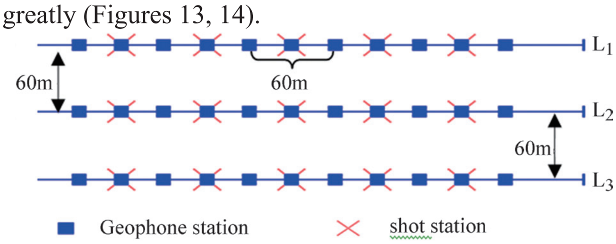


Figure 12
3 Lines and 3 Shots Geometry Design

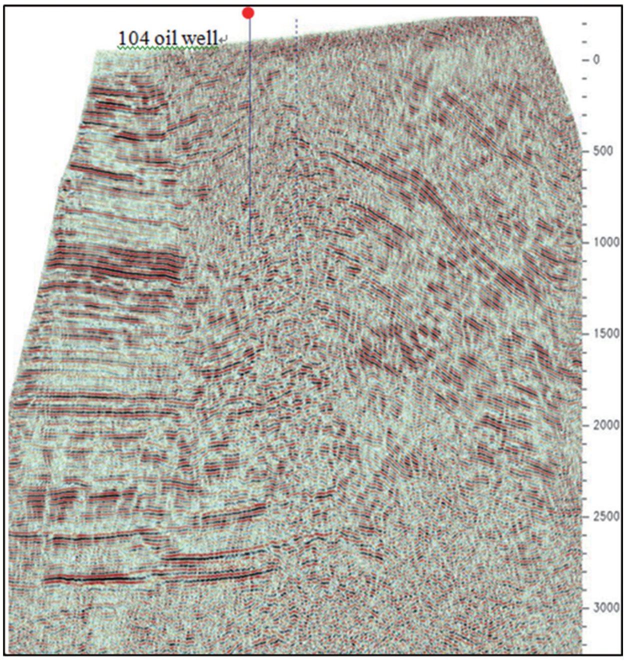


Figure 13
Seismic Section of the Wide-Line (2 Lines of 2 Shots), 2007

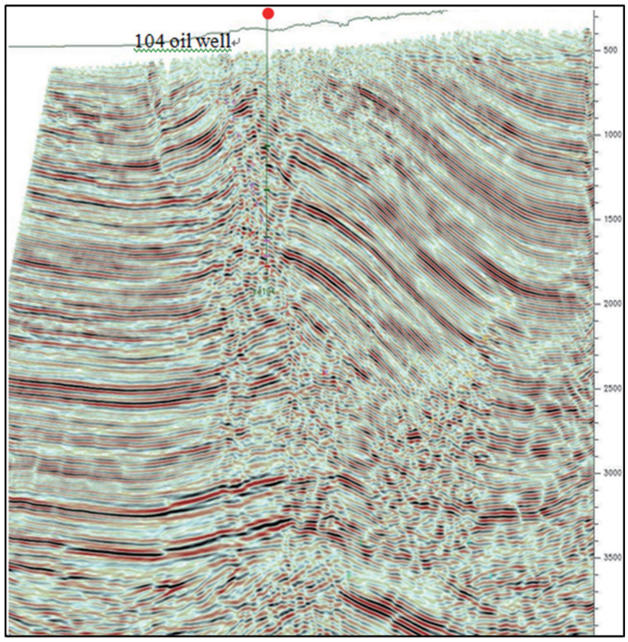


Figure 14
3D Seismic Section, 2011 (the Same Location of the Line, Figure 13)

3.4 Static Correction Technique

The difficulties of the seismic exploration are deepened further with the going of the acquisition in mountainous area. The importance is realized gradually by the geophysicists that the technique of the static correction plays an important role for improving the signal-to-noise ratio of seismic data. The low-velocity-layer is rather thick in YXL area. According to near-surface tomography model (see Figure 10), the thickness of the low-velocity-layer changing is greatly when velocity of interface is to 2300 m/s, the maximum thickness is about 500 m. Selecting the 17 up-holes survey (in the range of 70-150 m maximum depth), from the data of up-hole survey time-depth relation (see Figure 15), the velocity error of different depth is in the range of ±150 m/s when velocity of sub-weathered layer reaches to 1800-2000 m/s. So, there just is the difference of the thickness in near-surface layer, the variation of the lateral velocity is less. From the static correction curve of DWS (Figure 16), the tomography static and the elevation static correction curve is similar. And there is the difference of the corrections times only caused by the variations of the thickness in the low-velocity-layer.

Therefore, the stable velocity interface of the sub-weathered layers to be found, the problems of the static corrections can be solved the in the complex surface conditions. The near-surface tomography model is inversed and datum static value is calculated with the first-arrival time to resolve the static correction problems of the middle and long wavelength. On the base of this reiteration and fine-tune the model speed of near-surface. The equations solutions convergence and the residual static value (short wavelength) of the refraction is estimated. The quality of stack section is further improved by the static correction technology (Figures 17 and 18).

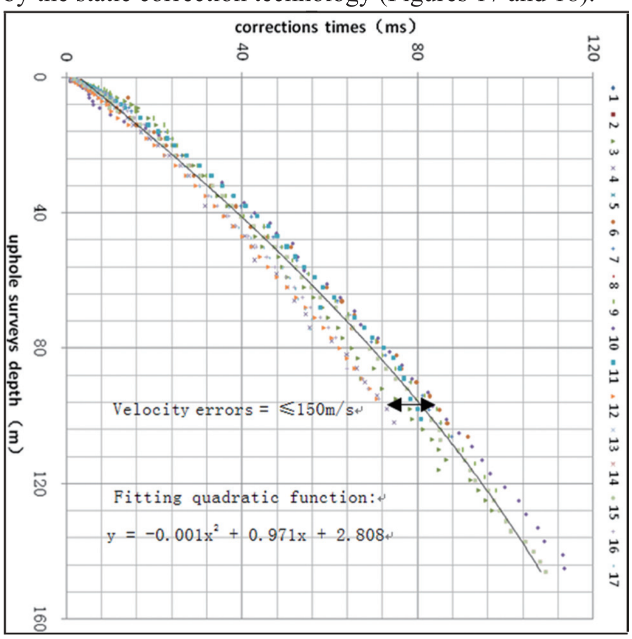


Figure 15
17 Deep Wells Microlog Time-Depth Chart YXL Area

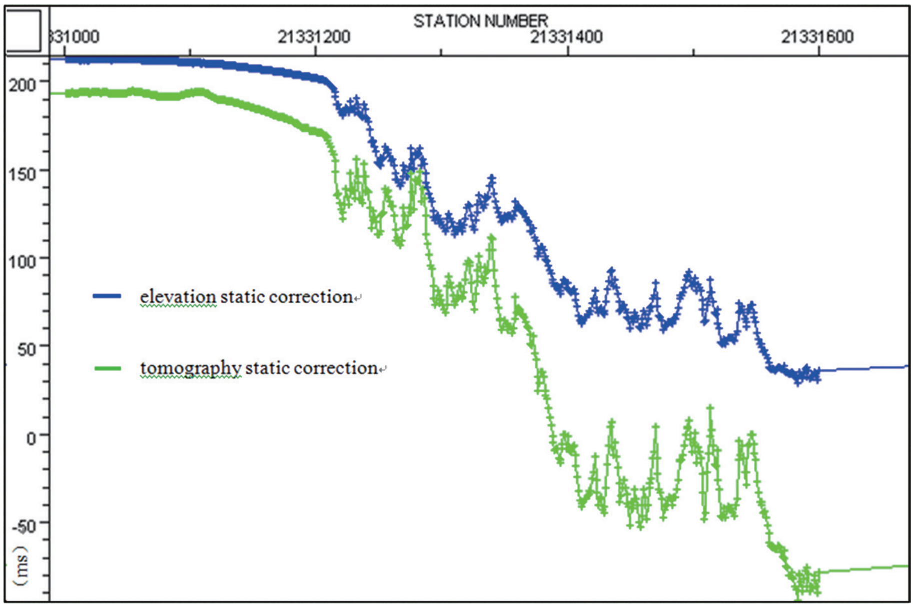


Figure 16
3D Seismic Static Correction Curve DWS Field

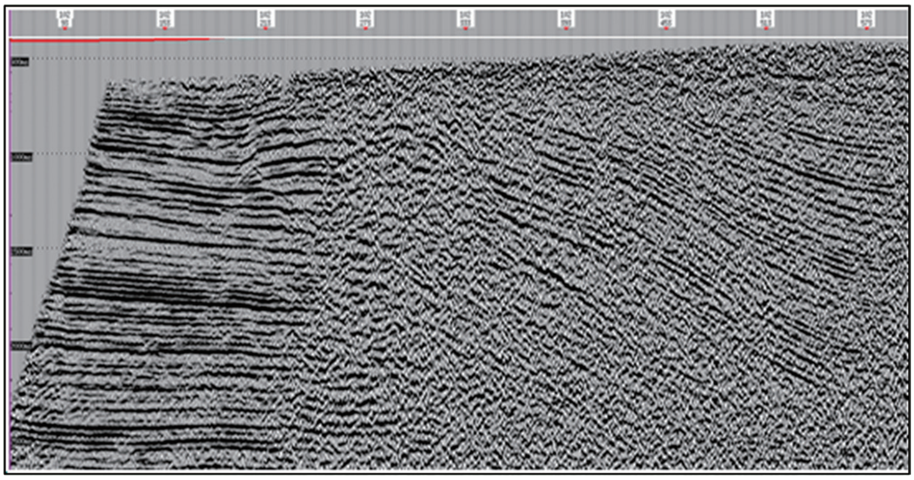


Figure 17
After Datum (Elevation) Static Correction Section for 3D Seismic Line YSHS

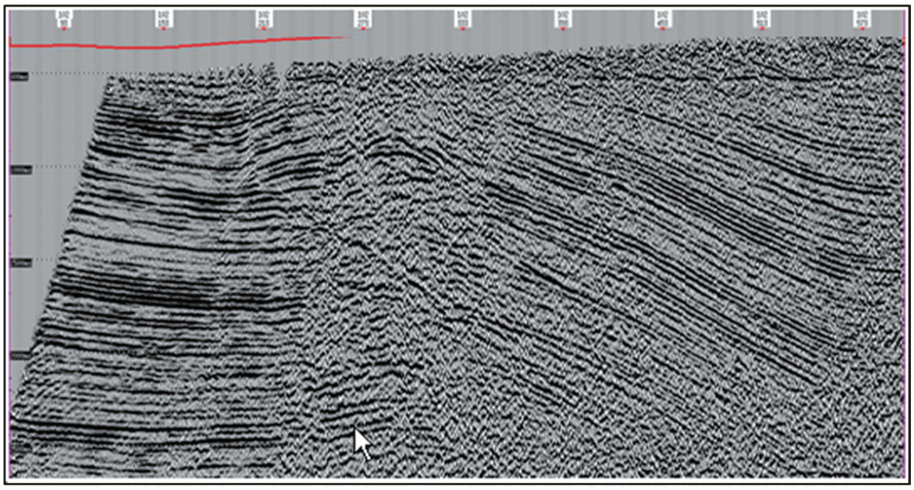


Figure 18
The Section of Datum Static Correction (Tomography) and Refraction Residual Static Correction 3D Seismic Line YSHS

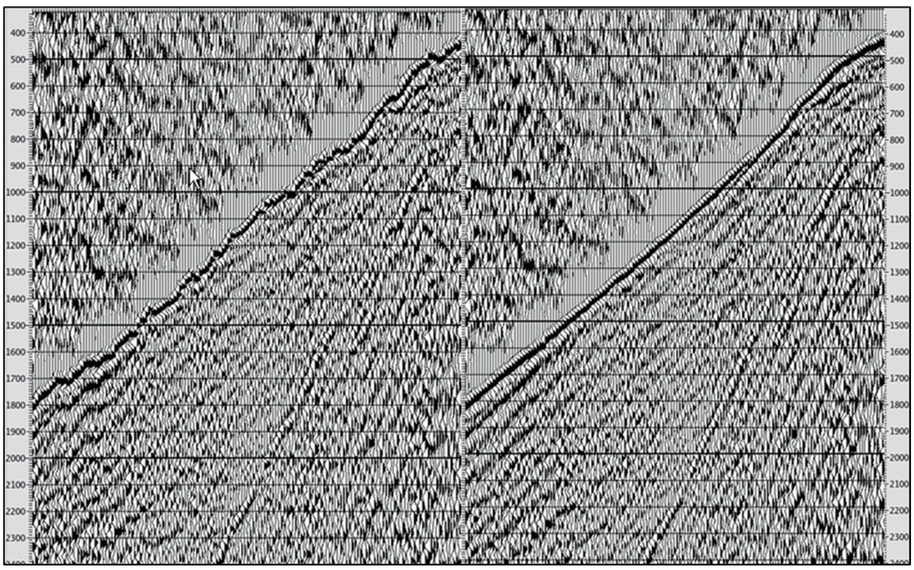
CONCLUSION

The analysis and the discussion were done on the paper with the previous seismic data of the interference wave characteristics, deep-hole shooting technique, indoor combination technology of the high density seismic sampling, array noise reduction technology, static correction technology etc. in YXL area Qaidam basin. The suggestions are given for seismic acquisition at the complex mountainous in YXL area latterly as follows:

(1) The subject of the seismic array to noise attenuation is that the regular surface wave and refraction wave are generated at the direction of propagation of the shot point and geophone point. But the side wave and the random interference wave are improved comparatively and without the fixed propagation direction. So, the areal pattern must be consideration. At present, the three-dimensional geometry design is the fascicular texture. The focus is the array figure to be selected. The designs of the azimuth distribution must be matched between the direction effects of the array and three-dimensional geometry in the bin. And the maximum noise attenuation effect of the seismic array could be produced best possible. But the array figure of "□","＋", "=","X","Y" can not be used at will. If the parameters design of the three-dimensional geometry are still adopted. According to the azimuth statistics of the geometry patterns , in the 0-360°distribution range, the azimuth angle for the shot-receiving pair the are concentrated mainly in the -25°～25°, -155°～ 155° (Figure 6). Selecting the rectangle graph is appropriate, its aspect ratio is consistent with the geometry. The optimization design of the geometry design for the seismic array noise reduction would be reached by the increasing numbers of the shot and geophone patterns in the receiving direction and the pattern interval adjusting (δ_x, δ_y) and substrate distance (L_x, L_y).

(2) In 2D seismic geometry design, the direction of each shot-receiving pair is same and the characteristics of the noise attenuation is consistent under the circumstance with the same numbers of the pattern and the coverage. In 3D seismic geometry design, the direction of each shot-receiving pair is different and the characteristics of the noise attenuation with the different directions are also differently. The weighted portfolio effect of the array noise attenuation in its bin is less than the array effect in the design of 2D geometry. This is already authenticated in the previous seismic at the field A of Qaidam basin (Luo *et al*., 2008). From the response analysis of the geometry design and pattern combination for the noise attenuation, the offset is well-distributed in the bin of 3D geometry under the circumstances of the same coverage. It has its own weakness in 2D wide line design. The same offset distribution is appeared. The numbers of the effective coverage is reduced greatly and the level stack response is affected.

(3) From the view of the data processing, the apparent actual effects of the technology for the static correction are obtained in complex mountainous area. The twisted first-break of the original seismic record is straightened after correction (Figure 19-YD field) and the influence of the near surface structure is further eliminated, and the surface wave, refraction wave with dispersion seriously becomes to regular (with coherence). It is propitious to filter the noise and densities of the velocity analysis indoor. And the qualities of the seismic section are improved further.



(a) (b)

Figure 19
The Variation Characteristics of the First Break and the Interference Wave Before (a) and After (b) Static Correction

(4) Any good design could be difficult to implement if the cost budget is beyond to the seismic acquisition. The drilling is so difficult and the cost of the shooting is high relatively in the complex mountainous exploration. With the shot-points (8m shallow wells) reducing (change the wells from 9 to 5) and the receiving-points increasing, the receiver line interval was reduced from 120m to 90m in present 3D seismic acquisition. The swaths and the coverage were increased. It is propitious to the stack array for the noise attenuation. The N times stacks are better than the N geophones array for the attenuation of the random noise[4]. The value of the signal-to-noise ratio is increased rapidly ($N^{1/2}$ times).

(5) The large pattern should be continued to play its role. In the case of the receiving interval (usually 30 m) reducing, the geophone array remains to the areal array (rectangular) mainly, the part superposition of the geophones in the adjacent seismic traces is allowed. And the array length in the direction of the shooting-receiving is pulled to 30-60 m. It is beneficial to attenuate the low frequency interference wave.

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