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Geometry Matching Technology of Non-Repeating Acquired Time-Lapse Seismic Data Processing

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Abstract

Different from the normal time-lapse seismic technology, time-lapse seismic technology with non-repeating acquired data utilize existing multi-period seismic data with different geometries at different exploration period of the same area. Not only the change of reservoir parameters cause the property differences of two-period data but also the difference of geometries, this uncertainty has become a fundamental problem in application of time-lapse seismic technology. In order to solve this problem, this paper takes advantage of the 3D Gaussian beam simulating method for illumination analysis of reservoir model, then we analyzes the impacts of various parameters of geometry on receiving energy of reservoir, finally we put forward the main factors affecting imaging of reservoir : the distribution of offset and azimuth. Basing on this conclusion this paper established the work flow of geometry matching for non-repeating acquired seismic data. By processing real data in S block, this technology could effectively reduce the affects of geometry difference and obtain an obvious result, and also provide an idea to increase value of multi-period seismic data in old oil field.

Key words: Non-repeating acquisition; Time-lapse seismic; Geometry matching; Offset and azimuth

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INTRODUCTION

At present a large amount of oil and gas field exploration into the development phases, people realizes the importance of oil and gas reservoir monitoring for enhancing oil recovery. One of the effective ways is to make full use seismic data obtained in exploration stages to monitor the change in physical property of reservoir and the flow of oil-gas-water inside the rocks[1]. For different geological tasks, most old oil fields have finished 3D seismic data acquisition with different geometries many times in the same area. Extracting the change of reservoir characteristics from the change of seismic attribute with different geometries has very important practical significance for enhanced oil recovery ratio, the most important thing is that this way could achieve the result of time-lapse seismic instead of increasing seismic acquisition costs[2].

The non-repeating acquired seismic data in the same area used different acquisition geometries, which make the two phases of seismic data have great differences in fold and acquisition accuracy. So except the change in physical property of reservoir induced by oil exploitation, the differences of seismic data acquisition, especially the differences of geometry also result in property differences of seismic data[3]. If the differences of geometries is not be eliminated, it will not guarantee that the change in seismic property represent the change in physical property of reservoir.

1. THE IMPACT OF DIFFERENT GEOMETRY PARAMETERS ON THE IMAGING ENERGY OF TARGET LAYER

How to find out the main geometry parameters affecting illumination energy of target layer is the primary step to match seismic data with different geometries. In order to analysis the impact of geometry parameters on the result of time-lapse seismic processing, we established a 3D velocity model with size 15 km × 5 km × 5 km to make forward modeling, the velocity mode is built based on seismic sections of S area in China. Figure 1 shows a profile of 3D velocity model, velocity value of each layer is showed in the right part.

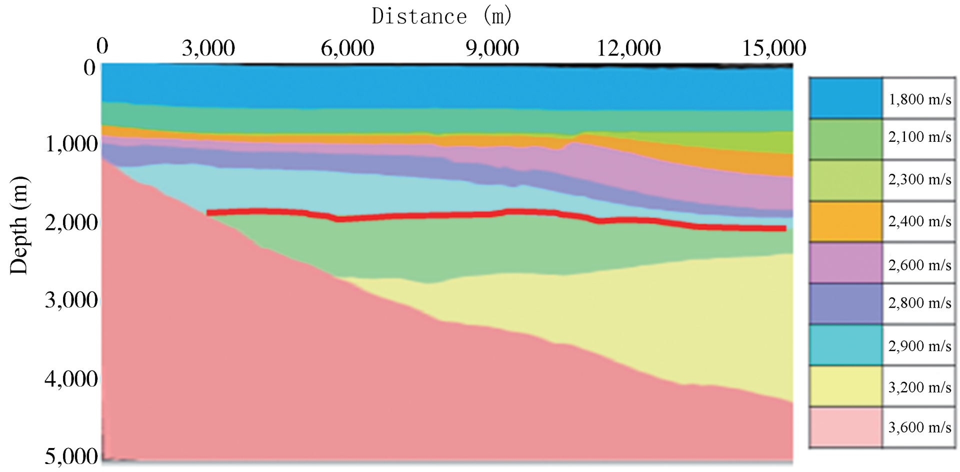


Figure 1
The Velocity Model of Reservoir in S Area

The target layer of analysis is shown with a red curve in Figure 1. The reservoir located in the right part of target layer, its depth ranges from 2,500 m to 3,000 m and its original velocity is 2,900 m/s.

3D Gaussian Beam method of forward modeling is used for analyzing illumination of seismic wave. Through comparing the illumination energy of bins in target layer, the impact of different geometry parameters on seismic characteristics of reservoir could be analyzed quantitatively. The analysis mainly focuses on five geometry parameters, they include group interval, interval of receiving lines, number of receiving lines, the minimum offset and maximum offset. When calculating illumination of target layer, we only change one parameter and let other parameters remain unchanged at the same time.

In addition, in order to eliminate the differences of received energy caused by inconsistent fold number, normalization processing is carried on amplitudes between before and after parameter changing in full fold region.

After calculating the illumination energy differences of target layer caused by different geometry parameters, the range of received energy of each bin in full fold region could be counted.

The mean square deviation of received energy of each bin in full fold region is used for assessing illumination uniformity of different geometries. The mean square deviation of received energy is defined as Equation (1)[4].

$$S_m = \sqrt{\sum_{i=1}^{M}\left(E_i - \bar{E}\right)^2 \Big/ (M-1)} \qquad m = 1, 2, \cdots, M \,. \tag{1}$$

M: Number of CDP in full fold region;

E_i: Received energy of each bin;

$\bar{E}$: The average energy of all CDP;

S_m: The mean square deviation of received energy of each bin.

After calculating illumination energy differences of target layer, which is caused by variant geometry parameters (group interval, interval of receiving lines, number of receiving lines, the minimum offset and maximum offset), quantitative relation between variation of geometry parameters and illumination energy differences could be summarized (Table 1). We could see the main influencing factors of illumination energy are the maximum offset and interval of receiving lines.

According to the same method, the quantitative relation between variation of geometry parameters and the mean square deviation of received energy could be summarized. We could see the main influencing factors of illumination energy uniformity are the maximum offset, interval of receiving lines and number of receiving lines.

Table 1
Statistics Result of Received Energy Difference When Changing Major Geometry Parameters

Geometry parameters	Fundamental value	Modifying value	Range of received energy differences	Range of the mean square deviation of received energy
Number of receiving lines	8	12	-41,000~22,000	0.0125~0.14
Group interval	50 m	25 m	-16,200~0	-0.004~0.009
Receiving line interval	100 m	50 m	-212,000~80,000	-0.135~0
Minimum offset	150 m	300 m	-31,500~0	-0.012~0.018
Maximum offset	3,306 m	4,741 m	-280,000~0	0.024~0.045

On the basis of the above analysis, the main geometry parameters influencing the received energy of target layer are the maximum offset and interval of receiving lines, so offset and azimuth of geometry should be mainly considered to match seismic data with different geometry.

2. THE PROCESSING METHOD OF GEOMETRIES MATCHING

According to the above study, this paper propose the processing method of geometries matching and build a basic processing flow for seismic data with inconsistent geometries (Figure 2). This flow mainly include two steps, the first step is to judge azimuth consistency of old and new geometries, if there are obvious differences of azimuth in old and new geometries, we should use common reflection angle gathers extracting technology. The second step is to judge offset consistency of old and new geometries, if there are obvious differences of offset in old and new geometries, we should reconstruct seismic traces in Tau-p domain. The following presentation will focus on those two technologies.

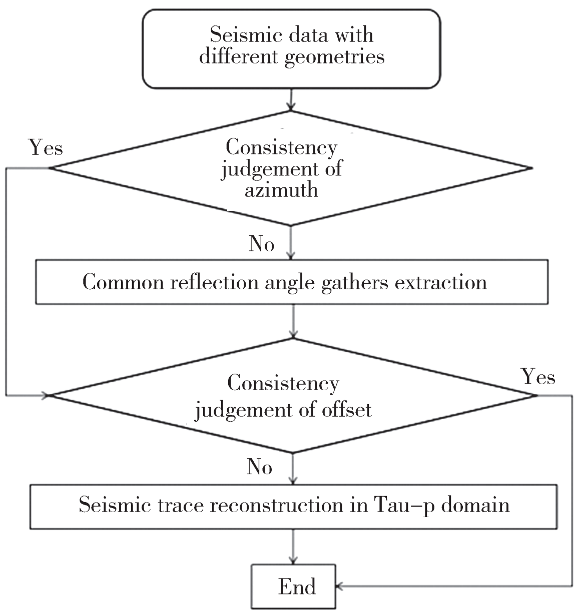


Figure 2
The Processing Flow of Geometry Matching in Non-Repeating Acquired Time-Lapse Seismic Data

3. COMMON REFLECTION ANGLE GATHERS EXTRACTION TECHNOLOGY

For the non-repeating acquired time-lapse seismic technique, because of the obvious geometry difference of non-repeating acquired seismic data, the same CMP (common middle point) are inconsistences in azimuth, offset and fold, which will bring unwished influence to the attributes differences of the non-repeating acquired seismic data. In the time-lapse seismic study, in order to increase the consistency of the non-repeating acquired data and ensure the reliability of attributes differences caused by reservoir variation, we aim at the distribution differences of offset and azimuth to extract CRP gathers, which through controlling the location of shot and receivers and incident angle. By this way, we can furthest eliminate the effect of different geometry and enhance the consistence of seismic response.

The method include two steps. The first step is to apply consistency processing for non-repeating acquired pre-stack seismic data, and exact CMP gathers. The second step is to extract CRP gathers from CMP gathers according to principle of consistent azimuth and offset. In the second step, CRP gather extracting must refer to the seismic data with lower fold, and extract CRP gathers from the seismic data with higher fold. CRP gathers extraction follow Equation (2)[5].

$$S_{ij} = \begin{cases} \sum_{a=0}^{n}\sum_{b=0}^{m} M_{ij}^{b} & (dis(B_{ij}^{a}, M_{ij}^{b}) \le \lambda) \\ 0 & (dis(B_{ij}^{a}, M_{ij}^{b}) > \lambda) \end{cases}. \quad (2)$$

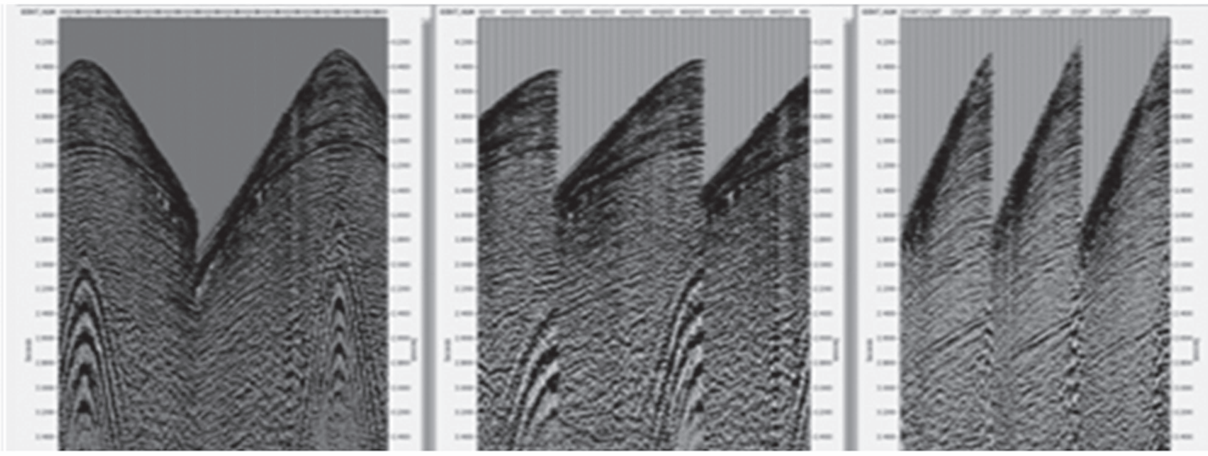
Each parameter's meaning as following: i is line number, j is trace number, n and m respectively are trace count of CMP gather at location (i, j) in early seismic data and later seismic data, B is the early seismic data, M is the later seismic data, S is the data after gather extraction, λ is the threshold value of distance.

4. SEISMIC DATA RECONSTRUCTION TECHNOLOGY IN TAU-P DOMAIN

After geometry degradation processing of the non-repeating acquired seismic data, we need to check consistance of offset and azimuth, if the result is "no" we must make them consistent through reconstructing the pre-stack seismic data[6]. We could reconstruct the losing data through extrapolating and interpolating using τ-p conversion[7-8], which will not obviously generate untrue events.

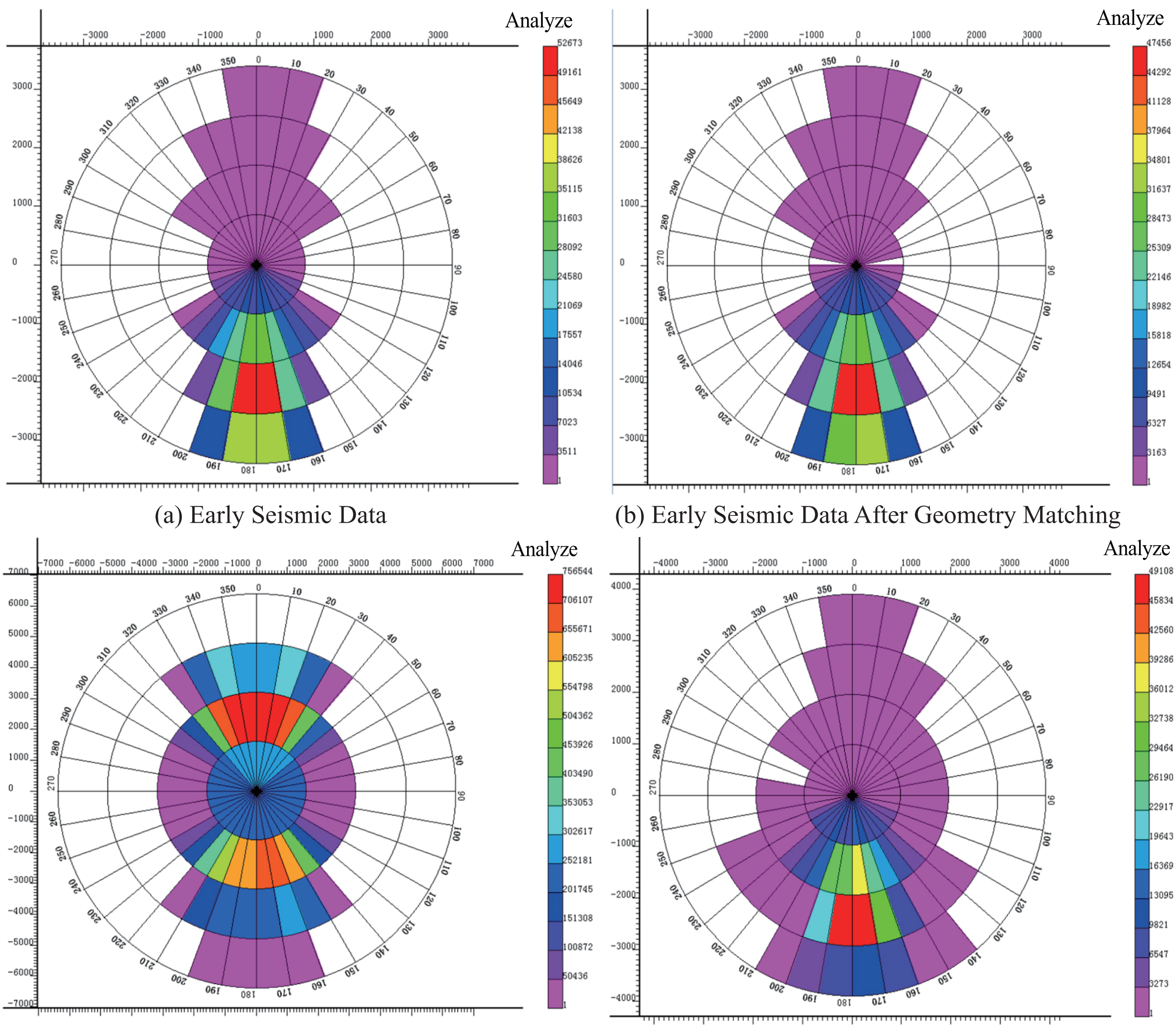
The first step is to replace absent seismic data with zero value, then the τ-p domain seismic data could be acquired through τ-p forward transformation. The second step is to expand the τ-p domain seismic data certain multiples and carry on τ-p inverse transformation, then the absent seismic data is reconstructed.

From the real example, the consistency of CMP gathers, offset and azimuth in non-repeating acquired seismic data were improved after common reflection gather extraction and seismic data reconstruction (Figures 3 and 4).



(a) Later Data (b) Matching Result of Later Data (c) Early Data

Figure 3
The Matching Result of Shot Record



(a) Early Seismic Data (b) Early Seismic Data After Geometry Matching

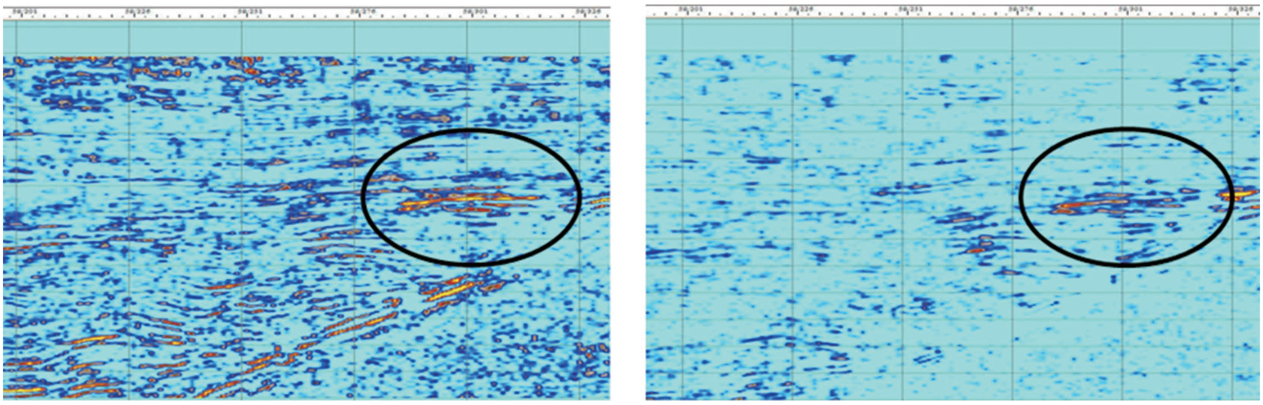
(c) Later Seismic Data (d) Later Seismic Data After Geometry Matching

Figure 4
The Azimuth and Offset Rose Diagram of Non-Repeating Acquired Seismic Data After Geometry Matching

5. EXAMPLES

S block belongs to heavy oil thermal mining area and the interval time of non-repeating acquired seismic data is very long. The seismic data in 1991 used conventional 3D acquisition with maximum offset 3,150 m, cable interval 150 m, the number of lines 4, grid 25 m × 50 m and fold 20. The seismic data in 2010 used high precision 3D acquisition with maximum offset 4,008 m, cable interval 200 m, the number of lines 20, grid 12.5 m × 25 m and fold 240. It is necessary to carry on the geometry consistency process because of the large differences of geometry property.

After applying geometry matching, the RMS differences in non-reservoir between later and early seismic data are reduced obviously, and the RMS differences in oil producing regions (black block area) is more obvious (Figure 6).



(a) Before Geometry Matching (b) After Geometry Matching

Figure 5
The RMS Difference Section Before and After Geometry Matching

During the development phase of S block, the RMS differences have very high sensitivity, and after consistency processing of geometry and other factors, the boundary defined by RMS property is in high accordance with the boundary of the cumulative oil production (Figure 7). It has great value for guiding the development of remaining oil.

In addition, during the development of steam stimulation in S block, T_0 time-lapse differences of the non-repeating acquired seismic data also has very high sensitivity to cumulative recovery volume, which is able to effectively outline the producing section of reservoir, and a good result of practical application is obtained (Figure 8).

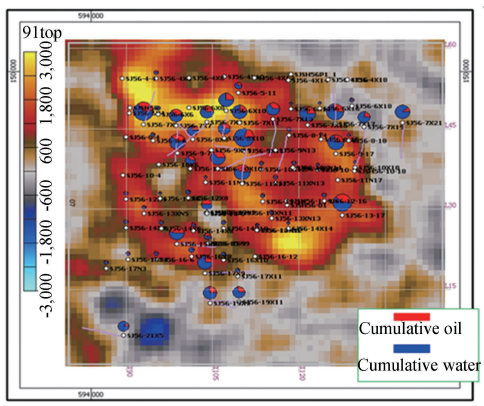
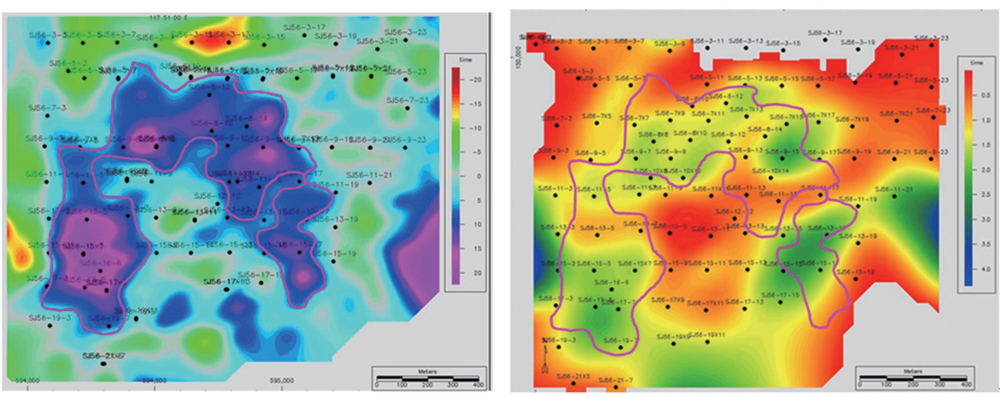


Figure 6
The Relationship Between RMS Attribute Delay Differences and Cumulative Oil Production



(a) A Horizon Slice of T_0 Time-Lapse Difference (b) A Horizon Slice of Cumulative Oil Production

Figure 7
Comparison of T_0 Time-Lapse Difference With Cumulative Oil Production

CONCLUSION

(a) By illumination analysis, maximum offset, number of cable and cable interval are the main factors that affect the value and uniformity of target layer imaging lighting energy, those factors could be resolved into offset and azimuth.

(b) The effect of the inconsistent acquisition can be eliminated effectively by common reflection angle gathers extraction technology and seismic data reconstruction technology in tau-p domain, that is decreasing the seismic response difference in section of non-reservoir and amplifying the seismic response difference in section of reservoir.

(c) After solving the differences of geometry, we could use multi-period unnormal 4D seismic data to carry on time-lapse seismic process, which could be used in reservoir monitoring and guiding the reservoir development.

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