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Time-lapse seismic monitoring for thin interbed reservoir in the Eastern China

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Summary

Time-lapse seismic technique is an effective method for dynamic monitoring and management of reservoir. It monitors dynamic changes of reservoirs with time by means of multiple seismic surveys. Application of this technique in thin interbed reservoir of land facies basin is an important research subject. In this paper, we introduce the time-lapse seismic monitoring of thin interbed reservoir in the Eastern China. The feasibility of time-lapse seismic monitoring is studied by rock-physics analysis and seismic modeling. After the equalization processing of time-lapse seismic data, the amplitude difference is obvious and thus the residual oil distribution is predicted.

Introduction

Time-lapse seismic monitoring is a technique to monitor reservoir with repeat seismic prospecting in different time during the period of reservoir development. The changes of seismic responses with time can character the changes of fluid properties in reservoir, which can describe the variation of lithologic parameters (such as porosity, permeability, saturation, pressure and temperature) in reservoir(Anderson, 1997).

In theoretical, the subtraction of time-lapse seismic data can directly image the dynamic fluid properties (fluid saturation, pressure, temperature and so on) of reservoir. In practice, however, the seismic data were acquired and processed in different time, which results in the variations in seismic profiles. These variations in seismic amplitude, velocity, frequency and phase are unexpected and undeserved in time-lapse seismic monitoring(Biondi, 1998). Thus the equalization of time-lapse seismic data should be done to obtain the two 3-D equalized data. The reasonable identity and difference of these data can analyze and interpret the dynamic variation in reservoir.

While, whether the time-lapse seismic monitoring technique can be used in thin interbed reservoir of land facies basin is not known, and it is an important research subject (Chen, 2006).

In this paper, time-lapse monitoring feasibility study for thin interbed reservoir is implemented through rock-physics analysis and seismic forward modeling. The time-lapse seismic data of ST block in Eastern China are processed and analyzed.

Seismic- geological setting and reservoir condition

In ST block, about 300 exploration and production wells were drilled in 1970 and 1980's. The sonic logging was not done in all wells. Thus the synthetic data with different frequency (40-75Hz) wavelet were done using resistivity and sonic logging curves in only six wells. These synthetic data are to calibrate the target layers T_{06}, T_{07}, T_1, T_{1-1} (top of Pu oil-bearing layer), Fu oil-bearing layer and T_2 (Yi, 1999).

In this area, markers T_1 and T_2 correspond to the reflection of the tops of Yao Formation and Quantou Formation respectively. These markers are very stable in whole region. The energy of reflections is strong, the continuity is good and features of waveform are obvious. Marker T_1 is above the Pu reservoir with duration about 837-934ms, and

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Marker T_2 is the bottom of the Pu reservoir and top of Quantou Formation. Thus they should not change with time. We use Marker T_1 as a standard layer in time-lapse seismic data processing and analyses.

T_{1-1} reflector corresponds to the reflection of the top of Pu reservoir. The apparent frequency of T_{1-1} reflector is about 50 Hz. The amplitude is middle and strong. The continuity is good. There are four phases between Pu reservoir and markerT_1. The time space between them is about 80ms. The features of waveform of Pu are obvious. The reflection time in seismic profile is from 920 to 1020ms. Pu reservoir is below theT_{1-1} reflector. It changes with time in time-lapse seismic monitoring. It should be processed carefully. T_2 marker corresponds to the reflection of the top of Quantou Formation. But Quantou Formation reservoir was not developed in 1980's and it should not be changed with time in time-lapse seismic monitoring. But it should be affected by Pu reservoir.

In this paper, Pu reservoir is main target in time-lapse seismic processing. It is main oil-bearing layer in ST block. Pu reservoir was penetrated in all wells. The capacity of some wells is high. Some wells are closed due to difficult production. In this area, Pu oil-bearing layer is thin interbed reservoir. The cumulative thickness of oil layer is about 55-66m. The thickness of sandstone of Pu reservoir is 1.6-20.3m. The effective thickness is 0.9-12.3m. The quality of seismic profile is good. The apparent frequency of Pu reservoir is about 65-70 Hz. Three events can be seen in profile clearly.

Rock-physics Analysis and seismic modeling

Up to now, there are a lot of studies on physical properties of pore fluid (Chen, 2008). Data from ST block is used to study seismic attributes characteristics of different fluids. Fig 1 depicts curves of pore fluid velocity variation with temperature and pressure.

A thin interbed geological model is built. The seismic properties calculated above are used to perform forward modeling. Dry rock frame moduli suitable to ST block are studied in the simulation. In this model, thickness of sand reservoir is 14.8m, and thickness of sand reservoir deducting three dry layers is 9.8m. Maximum thickness of single layer is 2.4m, while minimum thickness is 0.6m. Velocity and density of clay in the interbed are the same as surrounding rock. Two reflectors of shallow formation/clay and clay/deep formation are used to contrast and analyze variation of seismic characteristics of reservoir layer before and after water injection. Figure 2 is anomaly section after water injection. The modeling study shows that fluid replacement, variation of formation temperature and pressure caused by water injection will cause variations of seismic response. Figure 3 shows interference analysis of interbed by seismic modeling of different thicknesses of reservoir. Through interference analysis, we can study the influence of the interbed reservoir on time-lapse seismic response.

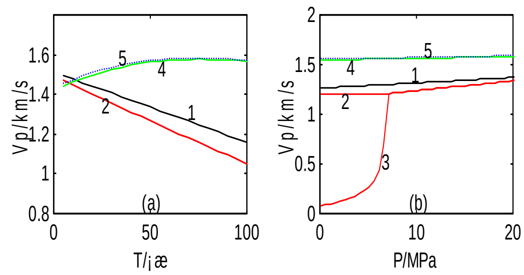

Figure 1: Velocity variations with temperature and pressure for Group Pu_1 pore fluids in TPT Block (1 represents degassed oil; 2 stands for oil with solution gas, 3 is oil with free gas; 4 represents fresh water; 5 is brine.)

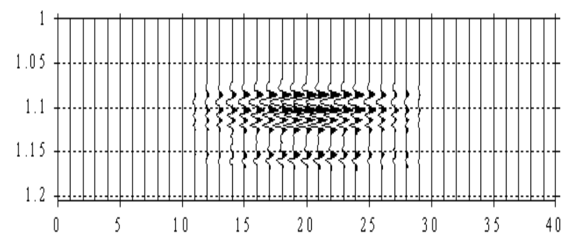

Figure 2: Seismic anomaly section after water injection

Time-lapse seismic data

In ST block, the digital detailed survey was done in 1988. Again, the high-resolution development seismic survey was done in 1996 in the same area. The 2-D seismic profiles of 1988 and 1996 can be used to perform time-lapse seismic research. In ST block, there are many production wells. Thus the block is suitable for time-lapse seismic monitoring. The main reflectors in the block are T_{06}, T_{07}, T_1 and T_{1-1}. The main target reservoirs are Pu oil-bearing layers. Figure 4 shows seismic profile and target formation in this block.

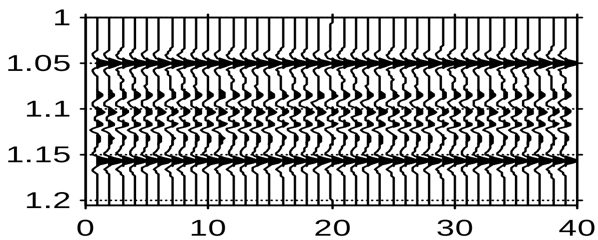

Figure 3: Interference analysis of interbed by seismic modeling of different thicknesses of reservoir

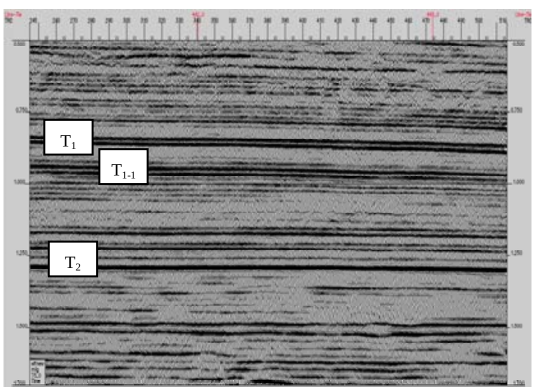

Figure 4: Seismic profile and target formation in this block

In both profiles of 1988 and 1996, the static properties of strata are generally consistent. The faults, structure trend and form interpreted in both profiles are almost the same, which reflects the consistency of old and new seismic data. These show that the data of old and new profiles have well repeatability.

However, time-lapse seismic data were acquired and processed in different time. The position and combination of the faults are not exactly the same in two profiles. Due to the progresses in 1999's survey, the resolution is improved, the positions of faults are clear and accurate, and the combination of faults changes a little.

The main reasons of above differences are: (a) The instruments and methods of acquisition are not the same, which results in the different quality of acquisition. (b) The processing flow and main parameters are more reasonable in second survey. The geological phenomena look more clear and reasonable in the new seismic profile.

In order to eliminate the differences in time-lapse seismic data due to the different processing flow and main parameters, we use the same software, flow and parameters to process the seismic data of 1988 and 1996. The repeatability of two profiles is largely improved.

Processing and analyses for the time-lapse seismic data

Processing and analyses for the time-lapse seismic data are carried out in ST block. The near or superposition surveys done in 1988 and 1996 are used as time-lapse seismic data.

The acquisition parameters of 2-D seismic data of 1988 are as follows. Shot point is in the end of line. Coverage time is 30. Minimum offset is 100m. The group interval is 25m. The sample rate is 1ms. The combination of geophones is linear. The number of geophones group is 24. The geophone interval is 2m.

The acquisition parameters of 2-D high-resolution seismic data of 1996 are as follows. Shot point is in the middle of line. Coverage time is 30. Minimum offset is 40m. The group interval is 20m. The sample rate is 1ms. The number of geophones group is 3. The geophone interval is 2m.

The acquisition parameters of two surveys are different and especially the trace interval is not the same. The CDP interval of surveys of 1988 and 1996 are 12.5m and 10m respectively. Thus the bin should be redesigned, which makes two surveys have the same CDP. In this paper, the same traces are selected from two profiles. One trace is selected from every four traces in 1988's profile and every five traces in 1996's profile, which may form a set of matched time-lapse seismic data.

Aiming at the differences of time, amplitude, frequency and phase in time-lapse seismic data, the equalization operator is designed to match two profiles. The designing principle is to take marker T_1 with window 837-934ms as a non-reservoir standard layer. The marker T_1 is above Pu reservoir and very stable in the whole area. It does not change with time in time-lapse seismic monitoring.

The equalization method is used to find a best match filter. This filter reforms effective source signal in every line, which makes it the same as the source signal of reference line. When the filter is obtained from non-reservoir window in profile, it will be applied to reservoir to correct two profiles. The differences of amplitude, frequency and phase in non-reservoir will be eliminated to a great extent, while the remained differences in reservoir should be interpreted as the changes caused by variation of oil, water and gas in reservoir (Chen, 2003). Figure 5 shows the comparison of the seismic profiles containing marker T_1 and Pu reservoir for two surveys after equalization. The identity of the marker T_1 in two profiles is largely improved.

Figure 5 also shows the difference profile of time-lapse seismic after equalization with taking marker T_1 as a non-reservoir standard layer. This figure indicates that the difference in marker T_1 as non-reservoir standard is eliminated. However, the differences in Pu reservoir still remain. The differences are related to distribution of wells, which accords with the actual situation.

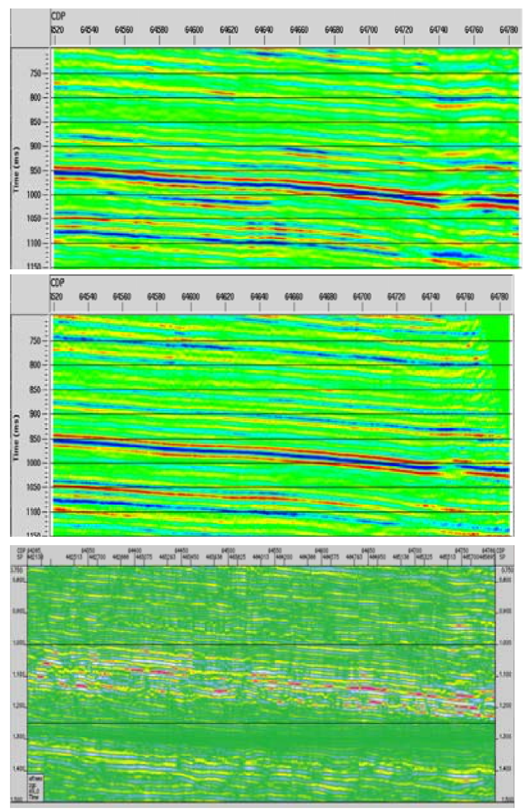

Figure 5: Time-lapse seismic data of line X surveyed in 1988(up), 1996(middle) after equalization (window 700-1150ms) and the amplitude difference between two time (down)

Figure 6 is residual oil distribution obtained by time-lapse seismic method, the red zone indicates oil area, the yellow zone indicates oil-water transition area, and the blue zone indicates water flood area.

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Conclusions

Our results indicate that the differences of time-lapse seismic data in non-reservoir can be eliminated with the equalization processing, and the differences of time-lapse seismic data occurs in faith in interbed reservoir. The differences are related to the distribution of production wells. Application of time-lapse seismic in Eastern China shows that the technique has great prospect in monitoring water flood reservoir.

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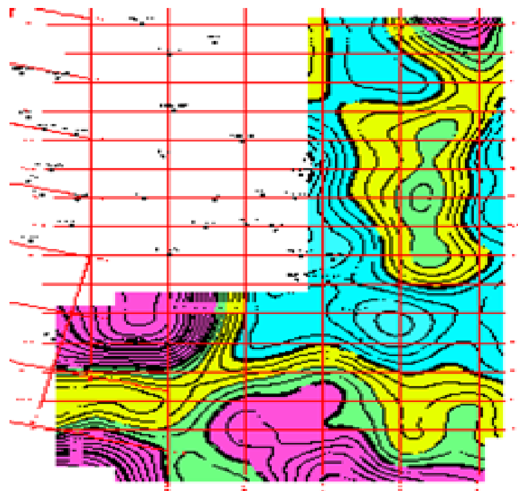

Figure 6: Residual oil distribution