Strategies for the acquisition and processing of high-fidelity time-lapse seismic data

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ABSTRACT

In some cases, the variations in the subsurface rock property with time can be observed during fluid flow process because of changes in stress, pore pressure, temperature, degree of consolidation, and fluid content. Detecting these changes via their influence on the in situ elastic properties serves as the basis for time-lapse monitoring. Acquisition and processing of high-fidelity time-lapse seismic data is the first and the most important step. Several 2-d time-lapse seismic surveys have been acquired over a steam assisted gravity drainage project to show how consistency of processing might affect the final stacked seismic image. The consistent choice of parameters in every step of processing is the key for the successful time-lapse monitoring. Cross-equalization is another important component in time-lapse seismic processing that transforms one seismic section to be comparable with the other. In cross-equalization, an operator can be computed trace by trace from the monitor survey that is then transformed to match the reference survey. Operators are designed in horizon-specific windows that exclude the reservoir zones. In the present study, we show how a lack of attention to detail in these matters can lead to incorrect interpretations of time-lapse results.

Purpose of time-lapse seismic monitoring

It's well known that the distribution of hydrocarbon within reservoirs is spatially heterogeneous being mainly determined by pore-fluid content, saturation, porosity, permeability, lithology, and structural control. These reservoir parameters and spatial variations can be used in the evaluation of total volume of hydrocarbon reserves in place, in predicting physical processes in the reservoir such as fluid flow and heat transfer, and in monitoring reservoir fluid production and recovery with time. Seismic technology is playing an important role in this aspect. The main idea is that several repeat seismic surveys are acquired in time-lapse mode to monitor reservoir production during fluid flow processes.

Rock physics transformation relates pore pressure, temperature, and multi-phase pore fluid saturation to seismic propagation velocities. Elastic wave theory demonstrates that the scattered wave amplitudes and the travel times of reflected seismic waves contain information about fluid-flow parameters, and more importantly, that time-varying aspects of fluid-flow can be isolated from static background geology and identified separately by images constructed from multiple time-lapse seismic data sets.

Overview of the local geology

Our target is located in a Lloydminster type reservoir in the vicinity of Alberta-Saskachewan border. The semi-consolidated sands of the Dina member form the primary reservoir. High temperature steam and gas is injected into a horizontal well to enhance oil recovery. Estuarine and marine shale and siltstones of the Cummings member cap laterally seal the Dina member. At the top of the Cumming is a 2~3 meters thick coal that forms a good regional stratigraphic marker.

Acquisition strategy

Two reflection lines are set up along different directions. One of the geophone lines runs west to east along north side of the property (240 channels), and the other geophone line runs north to south along west side of the property (216 channels). Together with these two setups, we shoot parallel to the geophones for the reflection surveys. Geophones are buried subsurface and covered with dirt to reduce noise. The buried geophone position can be easily located for the subsequent shooting, increasing consistency between experiments. All receivers and shot locations continue to be surveyed with a differential GPS survey repeated each deployment.

Noise problems of the raw data

The seismic data collected in this area is contaminated with coherent and stationary noise caused by the plant, pumps and pipelines. This type of noise is usually mixed together with reflection signal. Other noise, (such as high frequency air wave, low frequency ground roll), caused by surface condition, is usually inherent in the data. It can be separated from signal in the frequency domain. Another way to attenuate noise is by increasing stacking folds. The mid CMP position corresponds to maximum fold number. This means that signal/noise ratio is the highest at this position. The fold number decreases toward both sides. At the edge, noise becomes prominent. Obvious AVO effects are pronounced towards the ends of the reflected seismic horizon. When the time-lapse traces at the same CMP position are compared to each other, AVO effect can be put aside at the time.

Strategies of processing the time-lapse seismic data

In time-lapse seismic monitoring, possible changes can be detected within the reservoir when the variations of rock properties occur. How to preserve relative amplitude of the time-lapse seismic data is the essential issue. Landrø (1999) presented repeatability issues of 3-D VSP data, demonstrating that the repeatability increases as the accuracy of the positioning of the repeat survey increases. Our consistent shot locations and geophone locations between surveys guarantee repeatability to maximum degree. Ross et al. (1997)

presented shortcomings of nonuniform processing in time-lapse seismic monitoring. In our field experiments efforts are being made to maintain acquisition repeatability and focus on consistent processing. At the initial processing stage, regular and uniform processing sequences are chosen, which include trace edition, band-pass filter, refraction static corrections, detailed velocity analysis, normal move-out, surface consistent corrections, common mid-point stacking. At the second processing stage, cross-equalization is performed so that the time-lapse seismic data sets are comparable to each other. Ross, et al. (1996) presented a cross-equalization method, demonstrating the impact of the cross-equalization procedure on seismic data. Rickett, et al. (2001) presented in detail how to cross-equalize time-lapse seismic data in a case study from the Gulf of Mexico. Data alignment, amplitude balancing, bandwidth equalization, and phase matching are central to this issue.

Now some examples will be given to show the importance of consistent processing and cross-equalization. At the first processing stage, consistent parameters are chosen. Nonuniform parameters may lead to ambiguous and incorrect interpretation. This will be shown by the following example that how different parameters used in refraction static corrections will affect the same seismic data sets and the final processed image. In the first example there are small changes in the processing due to slight variations in the selection of refraction statics parameters with all other processing parameters being the same. Two final processed images are shown in figure 1 (top and middle frame). When the middle frame is subtracted from the top frame, the direct difference section is computed which is shown at the bottom frame. The amplitude is not zero everywhere. These amplitude variations are not caused by the subsurface rock property variations, but simply by the use of different parameters in the estimation of refraction statics. In this case, the difference result has no physical meaning but can be misinterpreted. Consequently, it is crucial to apply consistent parameters and uniform processing in time-lapse seismic monitoring in every step.

Cross-equalization is another important component in time-lapse seismic processing. The basic principle is to transform one seismic section so that it is comparable with the other section (Ross et al., 1996). In cross-equalization, an operator is extracted from the monitoring survey and reference survey. Then apply the extracted operator to the monitoring survey so that the transformed monitoring survey is able to match the reference survey. Operators should be extracted in horizon-specific windows that exclude the reservoir zones. Figure 2 shows four time-lapse traces before and after cross-equalization. It is obvious that cross-equalization does minimize changes within the designed windows. Under the complete repeatability situations, residual reflector energy corresponding to static geology background should be zero. However, perfect repeatability will never happen in the real world. Therefore, it seems crucial to choose a proper window to estimate operators.

Results and analysis

Four processed profiles acquired at different times are shown in Figure 3 with their corresponding difference sections in Figure 4. From the geology information, it's known that the sand body is too thin to display any time shifts due to steam injection using velocity changes predicted on the basis of Gassmann's equation modeling and the greatest effect will only be in variations of the amplitude of the reflected event. From figure 3 and 4, we can see that for the most part there is very little signal in the difference profiles. No significant time shifting is observed. Small amplitude variations are shown on the subtracted sections. It should be noted that the data sets are acquired after the communication between the steam injection well and oil production well has been completely established. During this period, steam chamber grows very slowly under the ideal situations. Only small changes are possibly observed on the reflected seismic section. If uncertain factor is incorporated, further information is needed in order to perform quantitative interpretation. This is beyond the scope of the present paper. Despite the lack of a strong signal, however, we are confident we were able to both acquire and process these data in a highly repeatable fashion. The negative result confirms the expectation that little signal should be seen in this reservoir. It is important to note, however, that only slight variations in processing produced a noticeable 'anomaly' in our earlier attempts at processing these data; a good deal of care must be made when carrying out such time lapse studies in thin and relatively stiff reservoirs.

Conclusions

Efforts are being made into increasing repeatability at the acquisition stage and accuracy at the processing stage. Good repeatability and uniform processing returns optimal results in time-lapse seismic monitoring.

References

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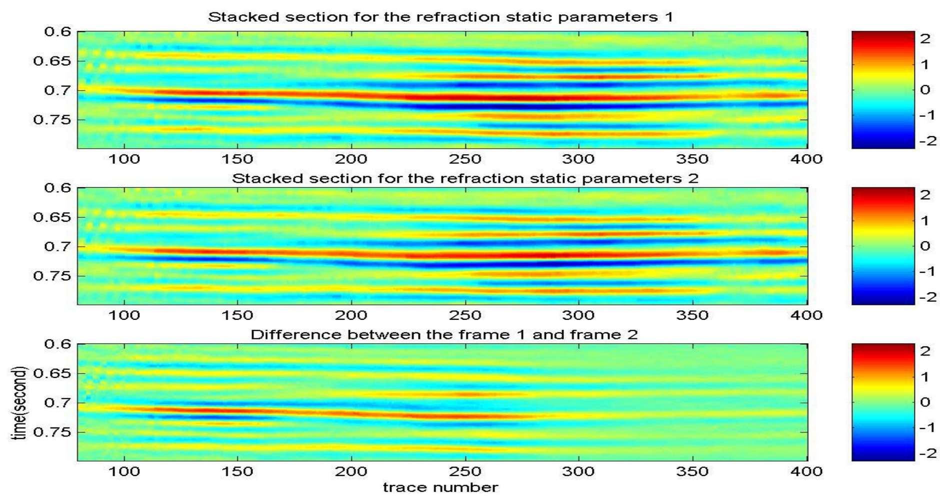

Fig. 1. The stacked seismic sections and their difference when choosing different parameters in the refraction static corrections. For the top frame, the parameters are: offset 110~600m, time range 120~350ms, weathering velocity=800m/s, replacement velocity 1750m/s, datum 700m; for the middle frame, the parameters are: offset 140~400m, time range 100~300ms, weathering velocity 800m/s, replacement velocity 1750m/s, datum 700m; for the bottom frame, subtraction between the top and middle frames.

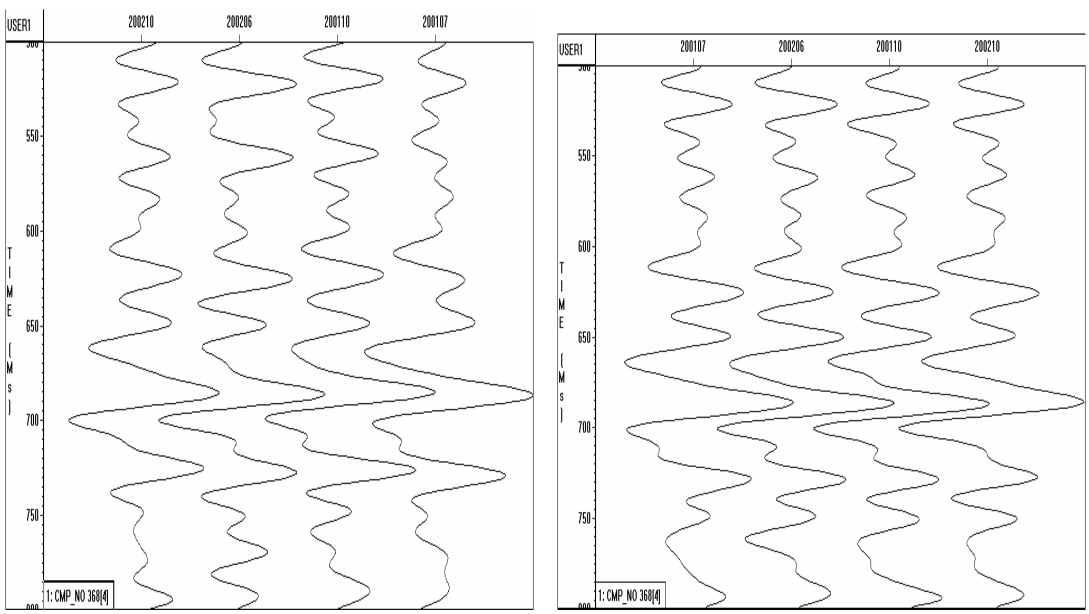

Fig. 2. Four time-lapse seismic trace before and after cross-equalization along north south direction

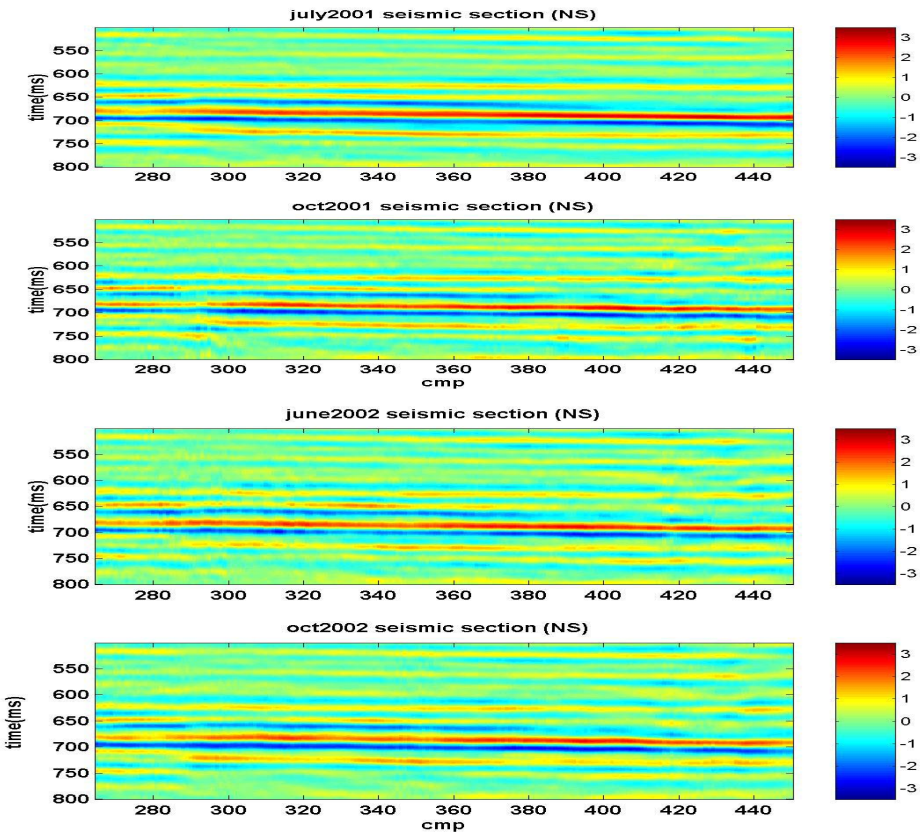

Fig. 3. Four time-lapse seismic sections acquired at different times

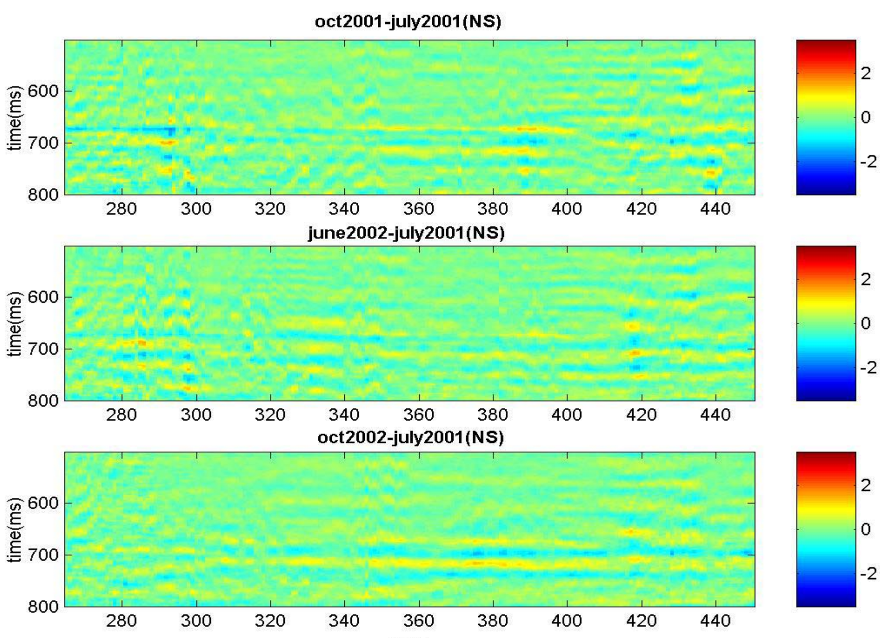

Fig. 4. Differencing sections along north-south direction, data from July2001 as slave survey, all the other survey as monitoring survey.