A Case Study: QC Analysis of Time-lapse Seismic Monitoring in a Heavy Oil Reservoir

Yajun Zhang* and Douglas R. Schmitt, University of Alberta, Edmonton, Canada

Abstract

Heavy oil reserves in the Western Canadian Sedminentary Basin are large but difficult to produce. Techniques, such as SAGD (steam assisted gravity drainage), have been applied to enhance heavy oil recovery. Time-lapse surveys during periods of injection or extraction have the potential to monitor variations in saturation, pressure, and temperature within the reservoir. Quality Control (QC) of the whole project is crutial for the sucessful time-lapse seimsic monitoring. Here, a case study from a Lloydminster reservoir illustrates the QC analysis. The process covers feasibility study, repeatability analysis of the acquisition data, and strategies of processing. Also an example is given to show how to apply QC analysis to diagonose and detect potential problems at each step during the time-lapse monitoring project.

Introduction

The East Senlac study area is located in the vicinity of the Alberta-Saskachewan border (Fig.1). The semi-consolidated sands of the Dina member (about 750 meters deep) form the primary reservoir whose thickness is about 8-15 m and which directly overlies the Paleozoic unconformity. The oil saturated zones generally overly water saturated zones. Estuarine and marine shales and siltstones of the Cummings member cap and laterally seal the Dina member. At the top of the Cumming member is a 2~3 meters thick coal that forms a good regional stratigraphic marker. During production, high temperature steam and methane gas is injected into a horizontal well to enhance oil recovery in a SAGD configuration, time lapse monitoring has the potential to track movement of such fluids.
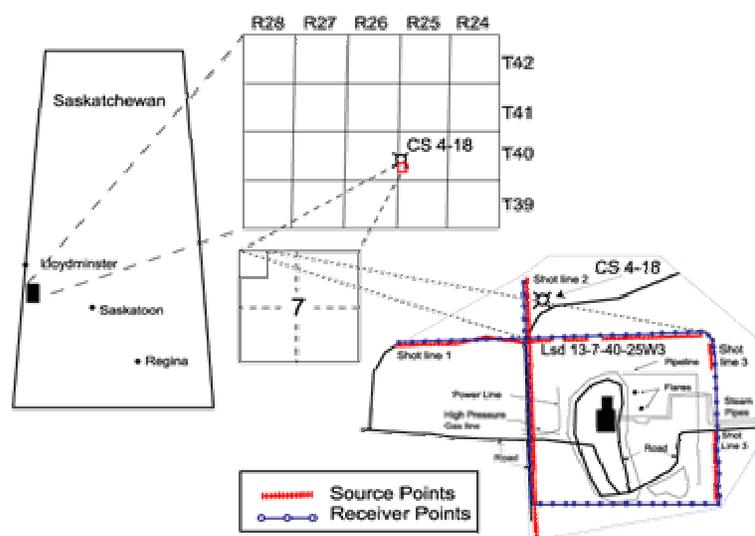

Fig. 1 The location of East Senlac Area and the corresponding setup seismic lines (courtesy of C.D. Rokosh.)

In our field experiments, special efforts have been made to maintain consistent shot and geophone positioning between surveys. Two reflection lines are set up along different directions. One of the geophone lines runs west to east along the north side of the property (240 channels), while the other geophone line runs north to south along the west side of the property (216 channels). With these two setups, we shoot parallel to the geophones for the reflection surveys. Geophones are covered with soil to reduce noise. The buried geophone positions were easily located and surveyed for the subsequent shooting, increasing consistency between the experiments. All receivers and shot locations were surveyed with differential GPS in each survey conducted. The same base crew and equipment allowed in the seven surveys carried out from late 1999 through mid 2002 allowed for a high degree of repeatability in both source and receiver positioning.

Feasibility Study

A rock physics substitutional analysis has been carried out by Theune and Schmitt (2003, 2004) using Gassmann's equation. According to this report which does not consider the possibility of geomechanical disruption, the effective bulk modulus of these relatively stiff sands do not change significantly when the heavy oil is replaced with gas phase steam or methane. However, the overall density deceases significantly, about 11% during the process of fluid substitution. This density variation constitutes the main factor that

can possibly affect seismic amplitude during the time-lapse seismic monitoring. After transforming the relevant rock properties into seismic velocities, the estimated compressional velocity deceases about 4.6%, while shear velocity increases about 6.9%. The resulting impedance variation is about 15%. Based on the estimated velocity information, the total time shifting of two-way traveling time for the compressional wave is less than 1 ms which is impossible to be observed on the reflected seismic data when acquired with 1ms sample rate. As such, we anticipate that changes in the reflected amplitudes, and not changes in travel-times, will provide the basic time-lapse information. This is supported by forward seismic models generated using a finite-difference algorithm with a geometry similar to that of the field experiments.

Repeatability Analysis

The repeatability of seismic data acquisition is crucial in time-lapse seismic monitoring. Previous case studies show that even small variations in water table, tides, ambient noise conditions, and source and geophone positioning to name a few, result in significant effects on time-lapse seismic data. Some of these problems can be overcome by careful replacement of sources and receiver positions. Other effects, such as those caused by annual near surface variations, cannot be overcome at the acquisition stage and must be ameliorated in processing. In our field experiment, as mentioned before, great care has been taken to maintain the repeatability of shot positioning and geophone positioning with differential GPS. Here only two sets of time-lapse geophone positions are shown (see Fig. 2). Similar high quality of repeatable geophone and shot positioning has also been acquired in the other data sets. Besides these efforts, great care has also been taken to maintain the repeatability of source signature in each survey (see Fig. 3). It is worthy to note here that the completely repeatable source wavelet is difficult to maintain in a practical field experiment due to changes in the quality of surface coupling during the year. What we can do about this is to try to maintain source signature as repeatable as possible in each shot and each survey. This will guarantee that most part of non-repeatability caused variations through exciting source are minimized.

QC of Time-lapse Seismic Data Processing and Some Pitfalls

In order to detect possible variations within the reservoir, the use of consistent processing parameters is necessary. It is also important to note that data dependent processing procedures, such as deconvolution, refraction statics, surface consistent statics, and migration may produce unexpected noise or artifacts within the supposedly static geologic background. Ross and Altan (1997) note that reflectors may be imaged to different positions by using different NMO and velocity functions, causing artifacts to appear in difference sections. Although this can be partially solved by applying static time corrections, it will be difficult to apply the same static correction method to lateral mispositioning and dynamic time shifts that vary as a function of depth. Vertically, even small time shifts less than one sample interval can cause false time-lapse events in difference sections. Such noise sensitive processing procedures should be avoided, especially in our situation of a thin reservoir in which small variations might be erased. Here I give an example from our own data to illustrate this problem. In this example (Figure 4), two slightly different refraction static corrections are used to process the exact same profile, the remaining processing stream was the same for both sections. Even with the minimal time shifts introduced in the statics there is a false signal that appears primarily because the reflection package returns from the complex package of reflections from the vicinity of the Paleozoic unconformity. Once each seismic data set has been uniformly processed, cross-equalization should be applied so that residual reflector energy is minimized and the time-lapse seismic surveys are comparable. Details of consistent processing and cross-equalization have been described in many papers (Ross et al.,1996; Rickett and Lumley, 2001; Zhang et al., 2002).
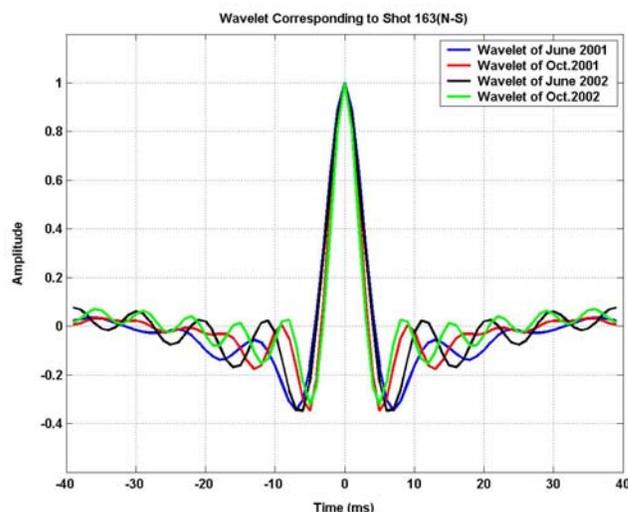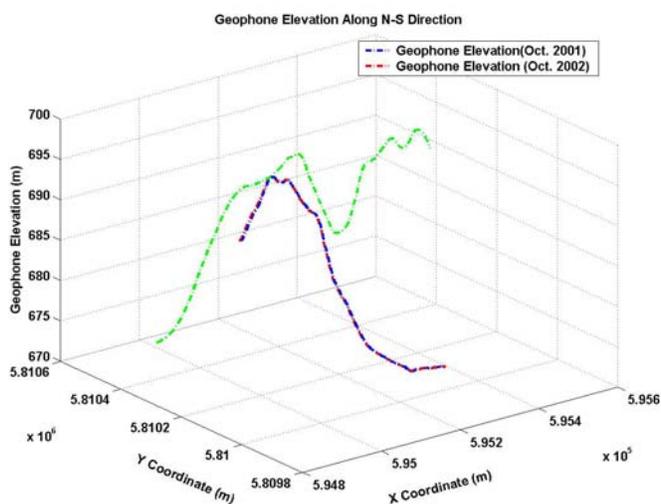

Fig. 2 Comparison of two sets of time-lapse geophone positioning.

Fig.3 Wavelets obtained at the same source-receiver pair at differentcalendar dates. Klauder wavelet is obtained from the filtered accelerometer ground force measurements used in the cross-correlation for a 12 Hz to 150-Hz sweep.
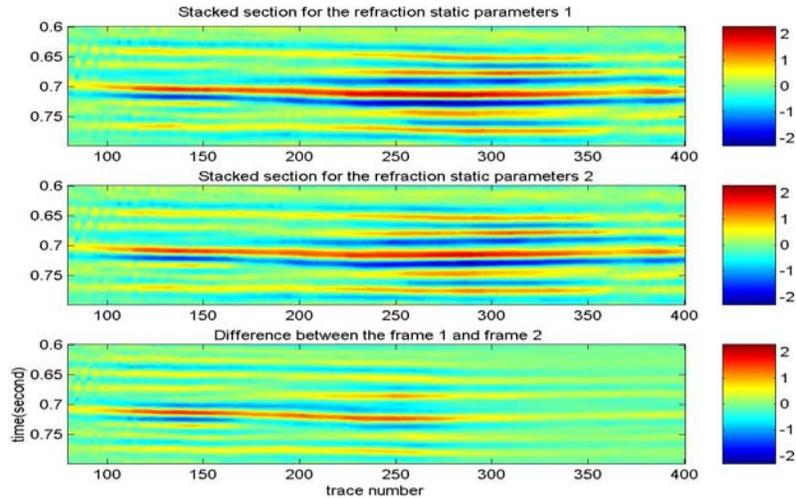
Fig. 4. The stacked seismic sections and their difference when choosing different parameters in the refraction static corrections. For the top frame, the parameters are: offset 110~600m, time range 120~350ms, weathering velocity=800m/s, replacement velocity 1750m/s, datum 700m; for the middle frame, the different parameters used are: offset 140~400m, time range 100~300ms; for the bottom frame, simple seismic differencing between the top and middle frames with false anomalies between traces 100 and 275.

Four processed profiles acquired at different times are shown in Figure 5. Their corresponding amplitude difference sections and energy variation curves are shown in Figure 6. From the geology information, it's known that the sand body is too thin to display any time shifts due to steam injection, and the greatest effect will only be in variations of the amplitude along the reflected event. From figure 5 and 6, we can see that for the most part very small signals exist 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 even under ideal situations. Only small variations are possibly observed on the reflected seismic section.
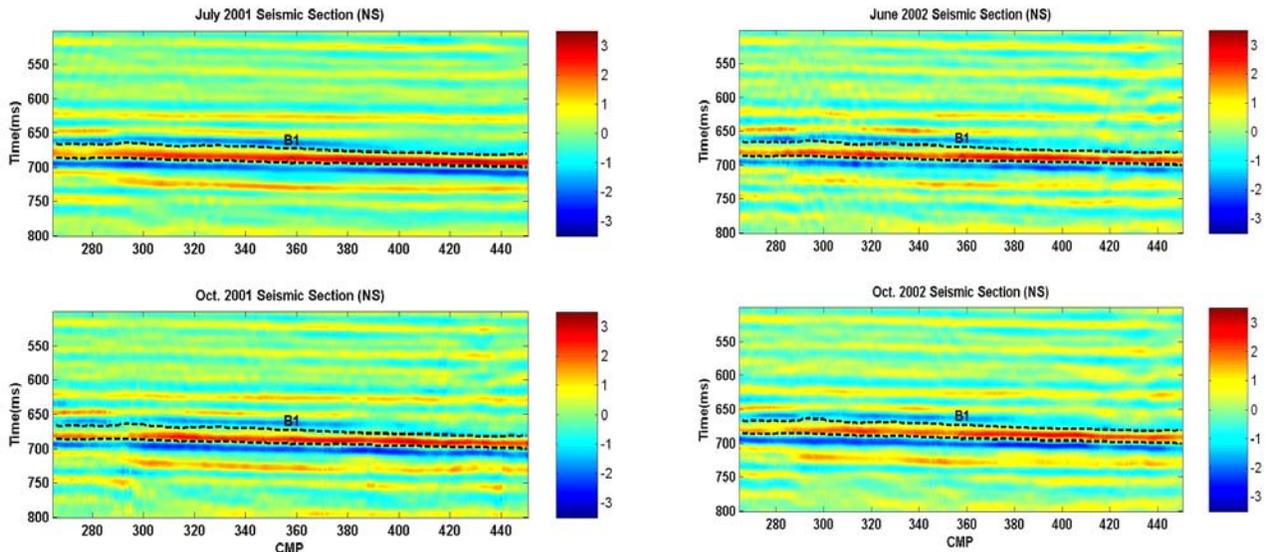

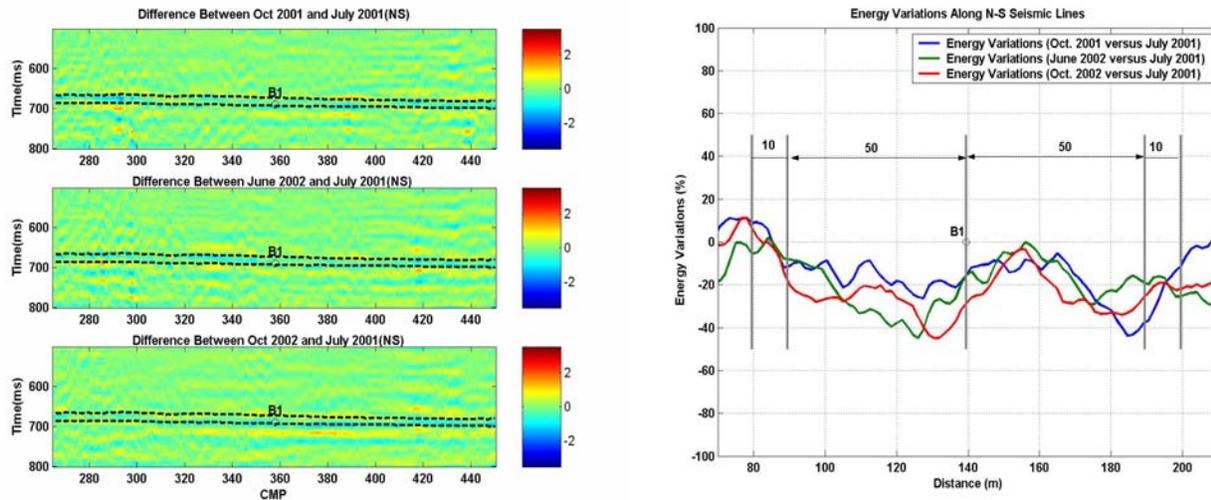Figure 5 Four time-lapse seismic sections acquired at different times

Fig.6 Amplitude difference and energy variations within the defined window along N-S seismic line direction. The data from July2001 was used as slave survey, the remaining surveys as monitoring surveys.

Conclusion

Through QC analysis, despite the lack of a strong signal, however, we are confident in the processed results 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 within thin and relatively stiff reservoirs.

Acknowledgement

References

Rickett, J. and Lumley, D. E., 2001, Cross-equalization data processing for time-lapse seismic reservoir monitoring: A case study from the Gulf of Mexico: Geophysics, Soc. of Expl. Geophys., 66, 1015-1025.

Ross, C. P. and Altan, M. S., 1997, Time-lapse seismic monitoring: Some shortcomings in nonuniform processing: The Leading Edge, 16, no. 06, 931-937.

Ross, C P., Cunningham, G. B., and Weber, D. P., 1996, Inside the cross-equalization black box: The Leading Edge, 15, 1233–1240.

Theune, U. and Schmitt, D.R., 2003, Characterization of the rock physics of the Senlac reservoir and feasibility testing of seismic monitoring: SHOC 2002-03 Symposium.

Theune, U. and Schmitt, D.R., 2004, A comparative case study of the effects of steam injection on seismic responses in differing heavy oilr eservoirs: implications for the feasibility of seismic monitoring, submitted Geophysics, Jan. 2004.

Zhang, Y., and Schmitt, D. R., 2002, Cross-equalization in time-lapse seismic data processing, 2002 CSEG Convention.