Time-lapse seismic analysis for the Blackfoot 1993, 1995, 1999 3C-3D seismic datasets

Han-xing Lu and Robert Stewart

INTRODUCTION

Repeated or time-lapse seismic surveying for reservoir monitoring attempts to image changes in the reservoir's fluid saturations, pressure, and temperature resulting from hydrocarbon production. The difference between seismic surveys acquired between the periods of production or intervention then can be interpreted in terms of the production-related changes in reservoir properties.

Time-lapse seismic analysis (a "4D" study) has been applied to three 3-D seismic surveys acquired over the Blackfoot area, Alberta in 1993, 1995 and 1999. In this paper, only the vertical component data processed into P-wave volumes are considered. The results indicate that there are some changes in the reservoir rock properties during production.

DATA ACQUISITION AND PROCESSING

The 1993 seismic survey shot by PanCanadian Resources covered a 10 x 10 km area and the output bin size was 30 x 30 m. The recorded seismic data is vertical component only. The 1995 seismic survey shot by The CREWES Project, University of Calgary covered the Glauconitic channel and Beaverhill Lake. The bin size was again 30 x 30 m, but in this case the seismic is 3C-3D data. The 1999 seismic survey shot by PanCanadian Resources covered a 2 x 4 km area, and the MEGA-bin technique was used in this survey, giving a natural bin size of 80 x 40 m. VectorSeis™ 3C digital geophones were tested in this survey.

The three seismic datasets were fully reprocessed (Lu, 1998; Li, 2001) by CREWES, but for time-lapse analysis these three datasets were extracted for the Glauconitic channel area only. The basemaps for these three extracted seismic sets are shown in Figure 1.

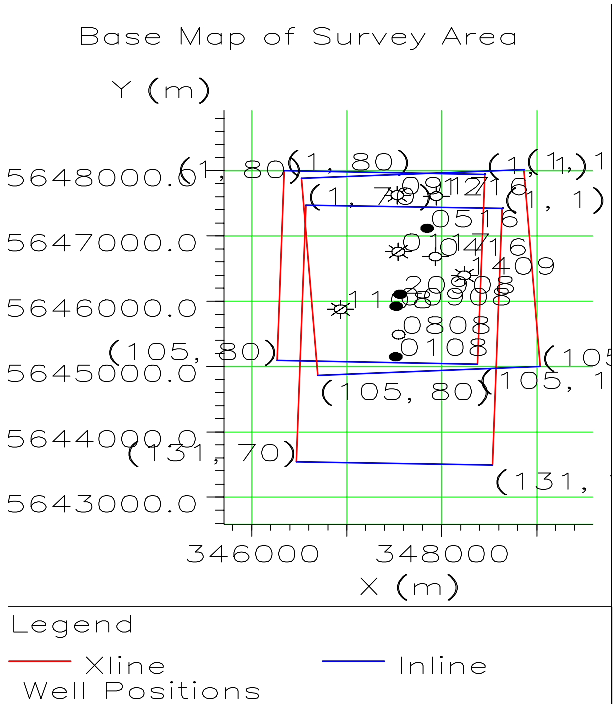


FIG. 1. Basemap for three seismic surveys (1993, 1995 and 1999).

The Blackfoot field, located fifty kilometers east of Calgary, Alberta, is in a Glauconitic incised valley system. This incised valley system of the Lower Cretaceous is subdivided into three phases (Figure 2). The upper and lower channels consist of mainly porous quartz sandstones, while the middle channel consists of relatively dense lithic sandstones. The upper and lower channels are the main reservoirs, which can be shale plugged at some locations. Oil is the primary hydrocarbon, although gas is also found in the upper channel and whenever it comes out of solution. Several seismic surveys in the area were completed in different years, thus providing grounds for a time-lapse interpretation

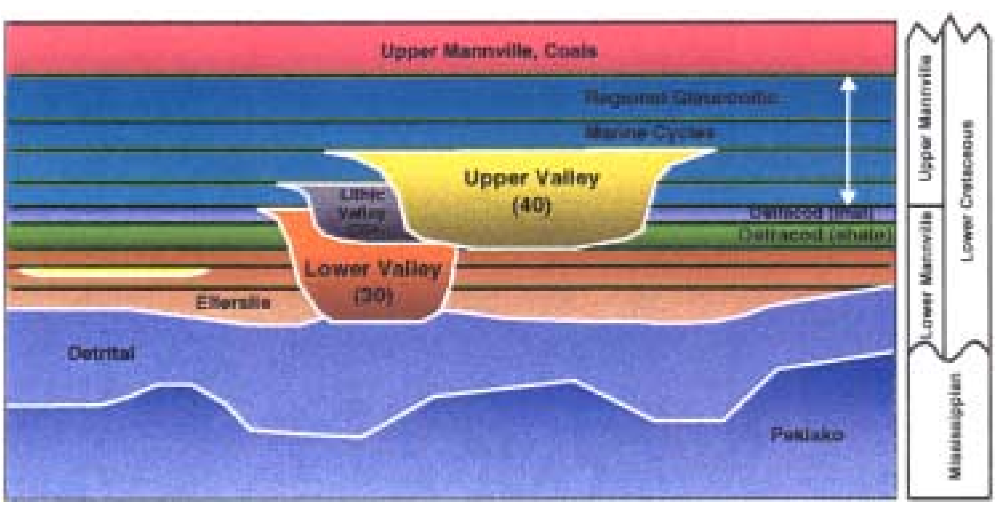


FIG. 2. A schematic view of the incised valley system for the Blackfoot field (Dufour et al., 1999).

RESULTS

The seismic processing targets are in the Lower Cretaceous Glauconitic channels, in the hydrocarbon reservoirs at depths around 1560m. The processing flows and parameters in the seismic processing for the three datasets were very similar, and the natural bin sizes were used in the processing. The post-stacked sections were re-gridded to 30 x 30 m for the 1999 seismic data. For these three migrated seismic sections, the Lower Mannville formation was flattened to 1050 ms. Time slices for the upper and lower channels are shown in Figure 3.

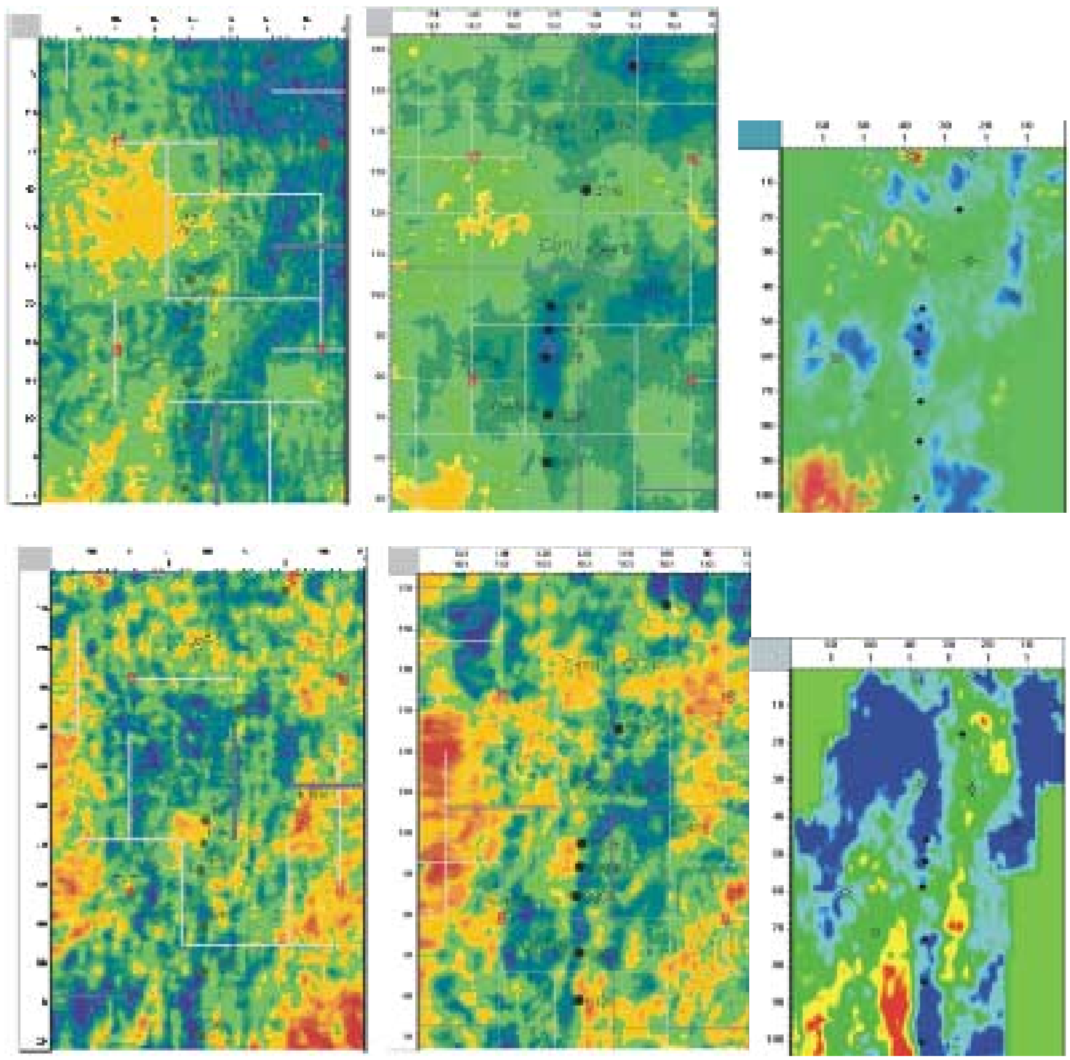


FIG. 3. Top panels are time slices for the upper channel (Glauconitic channel) of 1993, 1995 and 1999 from left to right; the lower panels are time slices for the lower channel of 1993, 1995 and 1999. The black dots represent production wells.

From Figure 3, the upper channel and the lower channel can be seen very clearly in these three datasets, but the time slices of the 1999 seismic are quite different from the 1993 and 1995 time slices, particularly for the lower channel. The image of the lower channel in the 1999 seismic data is smoother than in the other seismic data. In this display, a different color map was used in the 1999 seismic.

Only the vertical components were involved in this time-lapse analysis. The 1993 seismic data is treated as the base seismic, and the 1995 and 1999 seismic are monitoring seismic. After re-gridding the 1995 and 1999 seismic data based on the 1993 data (rotating, chopping and resizing the bin size of the 1995 and 1999 seismic) a new basemap is obtained which is shown in Figure 4.

After re-gridding, a cross-correlation was performed for the 1995 with the 1993 seismic within a window of 1050 ms - 1200 ms (this is our target time zone), and a maximum cross-correlation of 0.87 was obtained with a maximum time shift of 3.5 ms. The sample rate is 2 ms for both seismic, so this means that time shift is one sample only. The cross-correlation and time shift plots are shown in Figure 5. In the left panel of Figure 5, the small values of the cross correlation are clustered near producing wells. There are reservoir rock property changes related with gas or oil production. In the Glauconitic channel area, the cross-correlation coefficients are around 0.25-0.35, but out of the Glauconitic channel the coefficients are much higher (0.70-0.87). It thus appears that the rock properties have changed with time, causing seismic changes as well.

The match filter can be calculated trace-by-trace, or calculated globally. In our case, the match filter was calculated globally, and only those traces which had cross-correlation coefficients greater than 0.65 were involved. The match filter was applied to the 1995 re-gridded seismic data, including a phase shift and time shift, and then the difference calculated between the 1995 monitoring seismic and the 1993 base survey (1995-1993). The time slices were constructed from the difference. The time slice of the difference at the upper channel is shown on the top panel of Figure 6, and that of the lower channel on the lower panel.

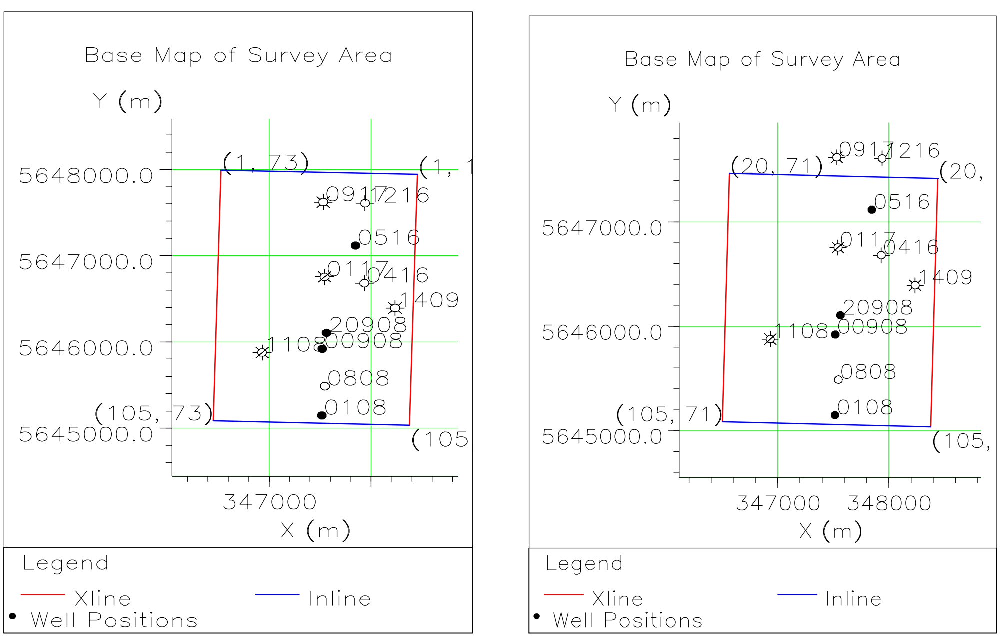


FIG. 4. The basemap for 1993, 1995 after re-gridding is shown on the left, and the basemap of 1993, 1999 after re-gridding is on the right; the in-line and cross-line numbers are the numbers of the base seismic (1993).

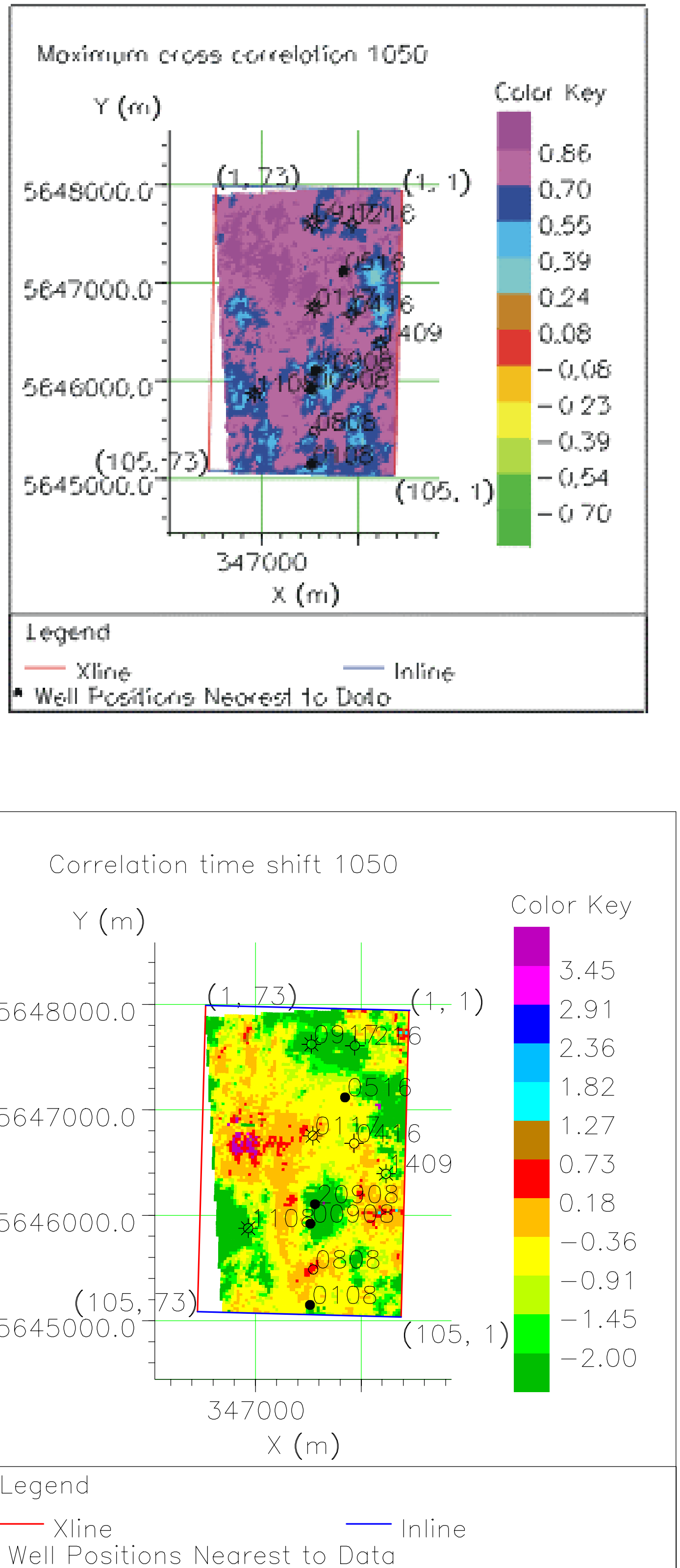
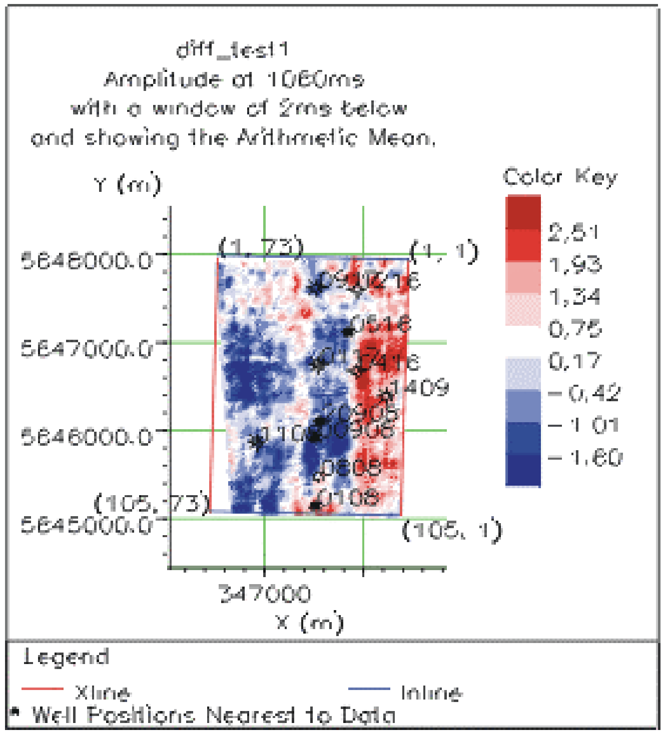


FIG. 5. The coefficients of the cross-correlation are in the top panel, and time shifts are in the lower panel.



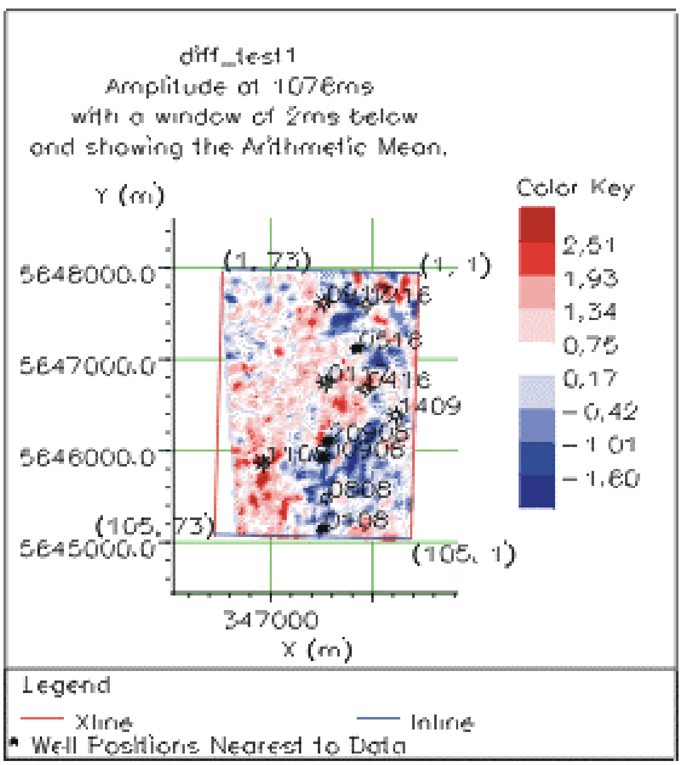
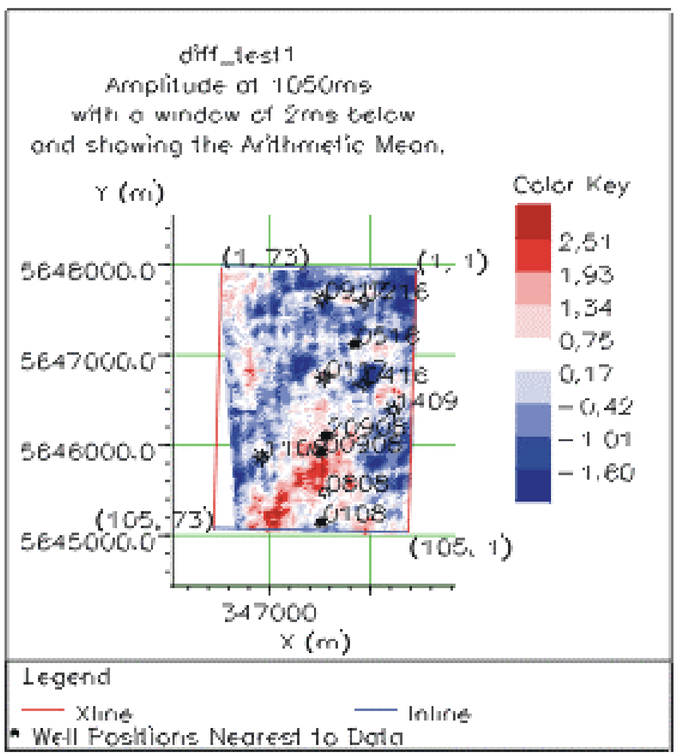
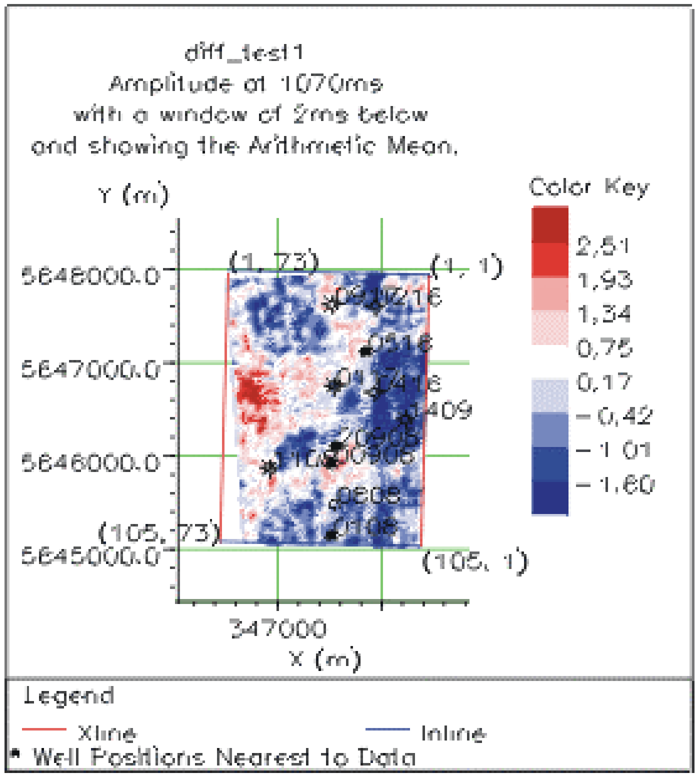


FIG. 6. The time slice of the difference of 1995-1993 at the upper channel is in the top panel; and time slice of the difference of 1995-1993 at the lower channel is in the lower panel.

From Figure 6, it can been seen that the largest seismic amplitude changes in the time slice at the time of 1060 ms and 1076 ms are in the Glauconitic channel area at the upper and lower channels respectively. It is possible that rock property changes with time have caused the seismic changes. It can be seen in Figure 5 that the changes in seismic at the upper channel are much clearer and wider than the changes at the lower channel. This seems logical in that there are gas production wells at the upper channel, but oil production wells at the lower channel. After gas production, the pore pressure and pore fluid properties (saturation, viscosity, compressibility and fluid type) change more than after oil production.

In Figure 7, there are three time slices, which are out of the channel target time zone, and there is no sign of the trend of the channel. From the log information, the reservoir of gas and oil is very thin (around 15 m), which would correspond to about 3-4 ms on the seismic data, so that when the time slices were created, a 2 ms interval was used for arithmetic mean.





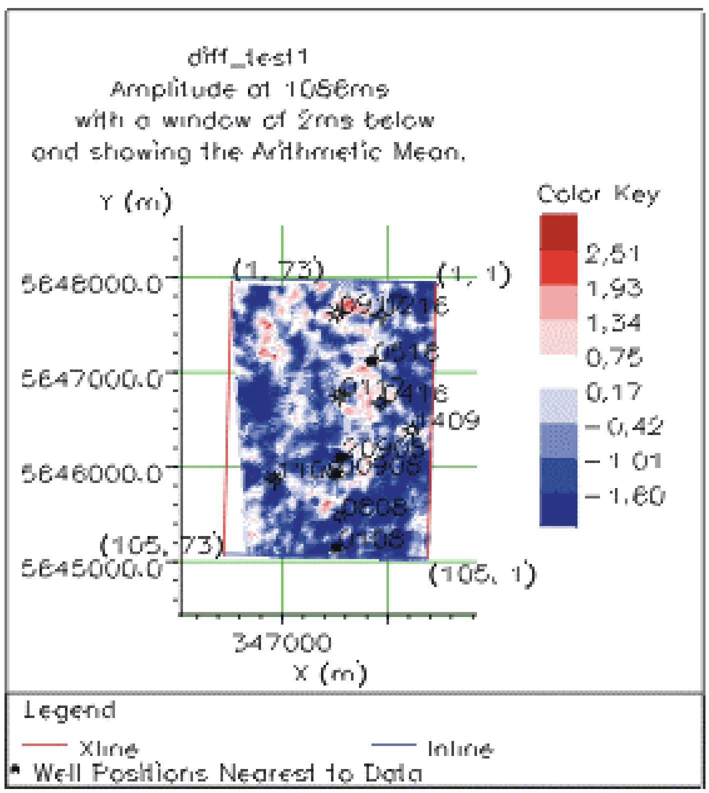


FIG. 7. The time slice at 1050ms is in the top panel; the time slice at 1070ms is in the middle, and the time slice at 1086ms is on the lower panel. All of the slices are out of the time zone of the targets.

The same procedure was used for the 1993 and 1999 seismic. The cross-correlation coefficients are shown on the upper panel in Figure 8, and time shifts are shown on the lower panel. The maximum cross-correlation coefficient is 0.72, much lower than the cross-correlation coefficient of 0.87 between 1993 and 1995 data. Most of the time shifts are within –5 - 5 ms (about 2 samples in the seismic), which we consider acceptable.

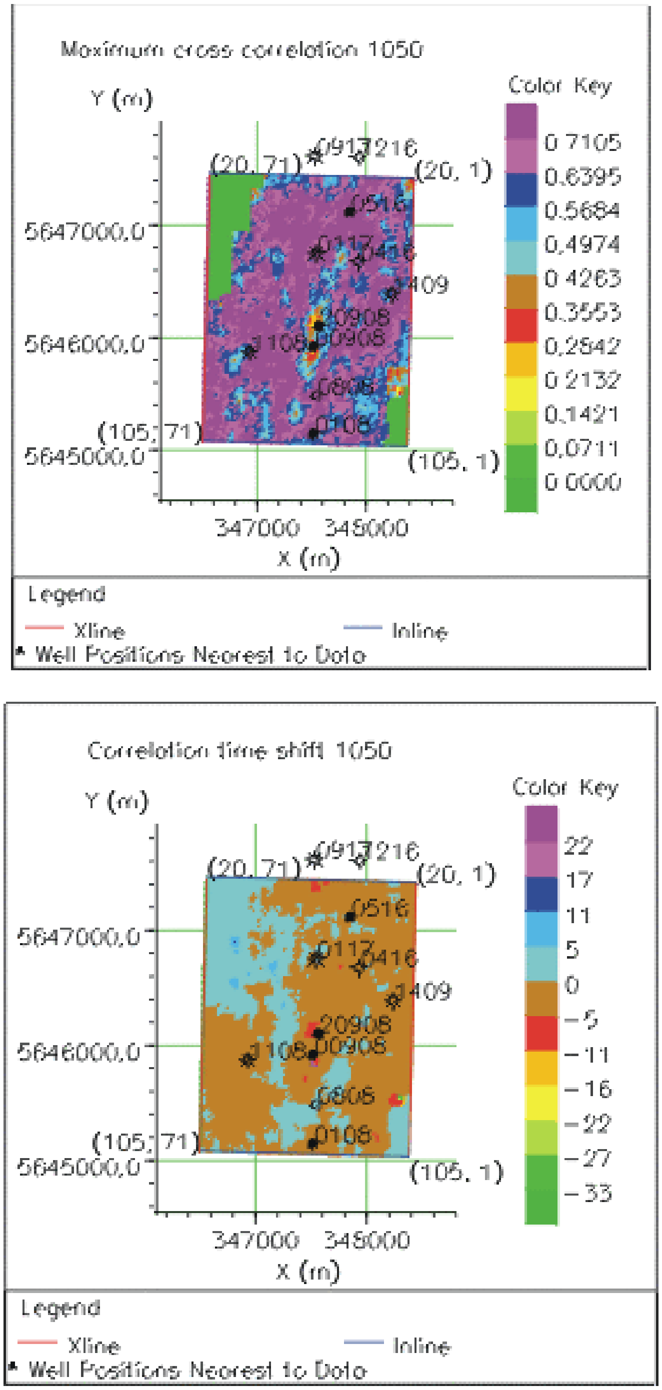


FIG. 8. The cross-correlation of 1993 and 1999 seismic data (time window is 1050-1200 ms) is shown in the upper panel; time shifts are in the lower panel.

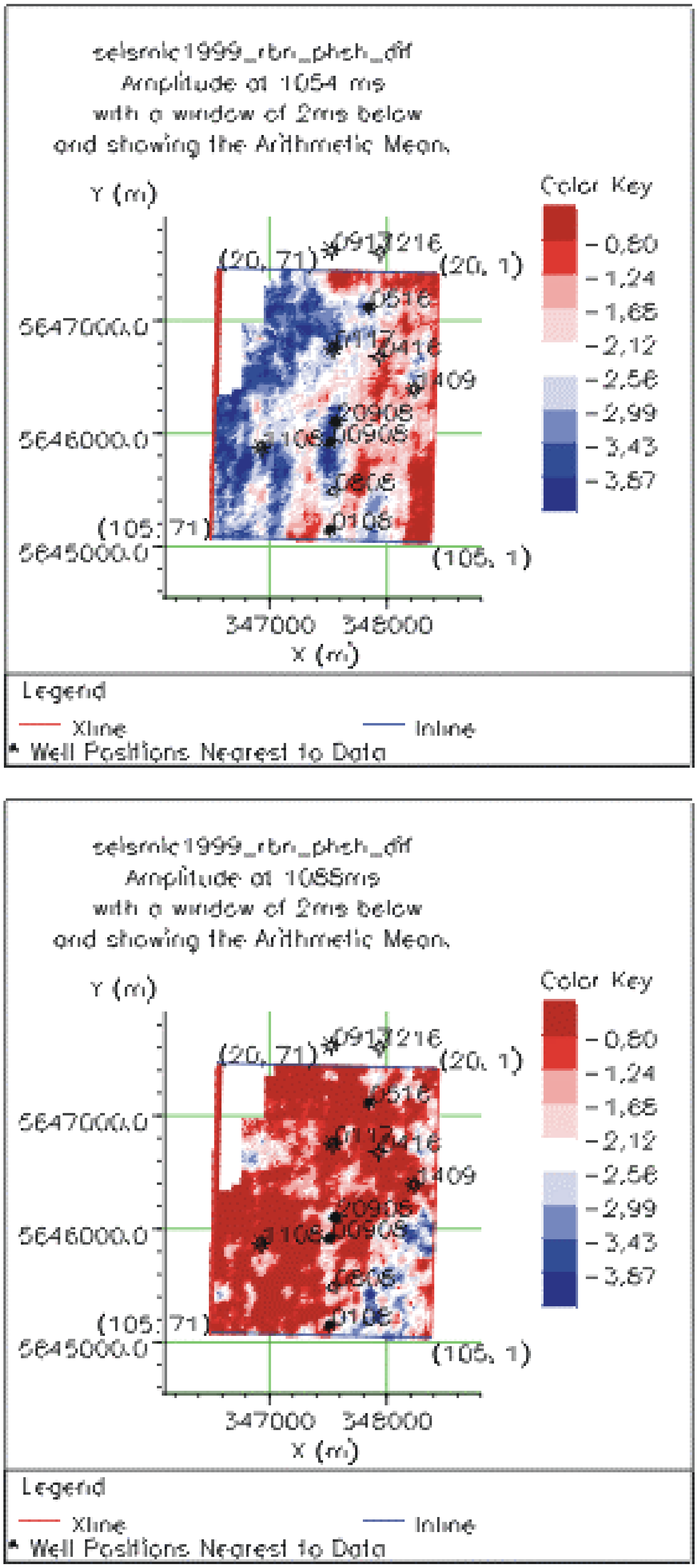


FIG. 9. The time slice of the difference of 1999-1993 at the upper channel is in the top panel; the time slice of the difference 1999-1993 at the lower channel is in the lower panel.

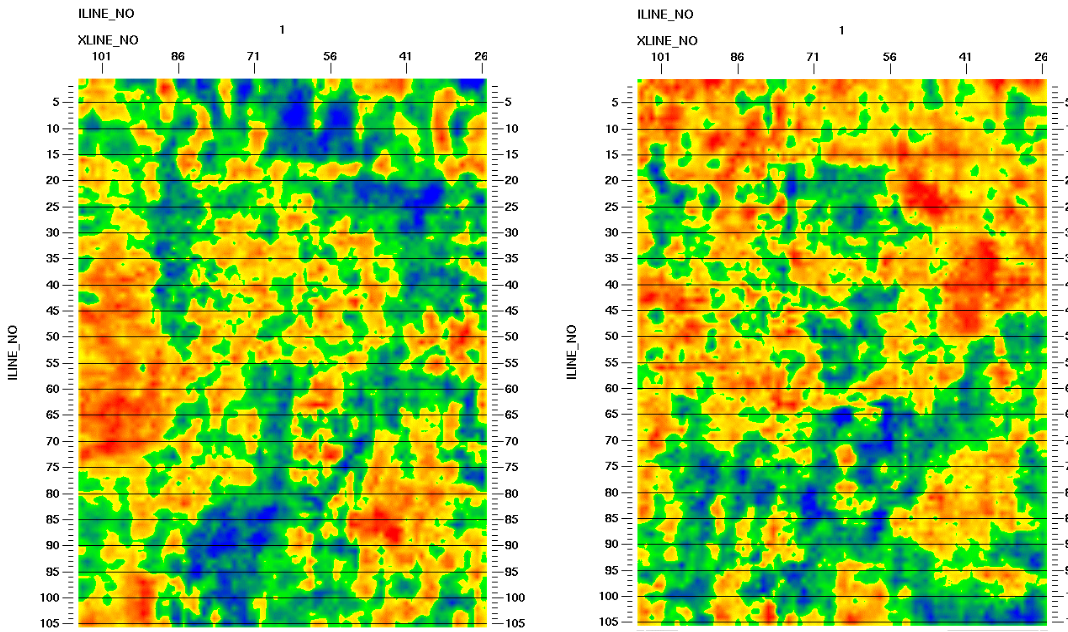


FIG. 10. Time slices of the difference 1995-1993 using the match filter obtained trace-by-trace. The time slice for the upper channel is on the left; and time slice for the lower channel is on the right.

As a comparison, the time slices for the difference 1995-1993 were calculated using a match filter obtained trace-by-trace. The window is from 800 ms to 1200 ms and employed a MATLAB routine from the CREWES seismic software. Compare the images in Figure 6 and Figure 10. Despite the use of different color maps, the similarity between these images still can be seen. This demonstrates that the difference persists, whether the match filter is calculated globally or trace-by-trace.

DISCUSSION

There have been a number of time-lapse seismic case studies in recent years, with many of the cases involving steam injection. This is because after steam injection the temperature in the reservoir area is much higher than in other areas, and this high temperature causes reservoir rock properties to change. It is easier to influence the seismic, so the time-lapse seismic as a tool to monitoring the gas or oil (or heavy oil) production.

There is a hypothesis that if the bulk modulus of the rock (K) is large, the seismic is not very sensitive to the change in the rock properties. In the Blackfoot case, no steam injection exists, and the target zone is quite deep (at around 1560m), and these factors caused some difficulties in the time-lapse seismic analysis. On the other hand, there are high quality 3D datasets in 1993, 1995 and 1999. After carefully reprocessing these three datasets, the seismic changes (differences between 1995 and 1993 (1995-1993) and between 1999 and 1993 (1999-1993)) are obvious in the reservoir area. However, these changes are not only from the reservoir rock property changes. If it were so, the seismic changes should occur at locations near the production wells, whereas the persistent results show that the changes are along the channel. There is still a puzzle here: can we eliminate all possible causes other than reservoir rock property changes? Time-lapse analysis for the radial component may solve this problem.

CONCLUSION

There are some changes in the rock properties with production, so there should be changes in the seismic as well. But actually what we see in the time slices of the differences for 1995-1993 and 1999-1993 are not only from rock property changes, but are also due to the different acquisition parameters, different noise background, and even different processing parameters. Even allowing for these factors though, (which cannot be eliminated from the seismic data), the trend along the channel still can be seen. Thus the results are still reliable to a degree.

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