Seismic Monitoring of “Hot” and “Cold” Heavy Oil Production

Laurence R. Lines - Dept. of Geology and Geophysics, University of Calgary

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Summary

Time-lapse seismology has proven to be a valuable tool in the characterization of reservoir conditions in enhanced oil production. Our collective research experiences with Athabasca, Cold Lake, and Lloydminster oil sands demonstrate the utility of seismic monitoring for mapping steam front zones. Due to seismic velocity decrease with temperature increase in oil sands, seismic monitoring can be achieved by time-lapse mapping of seismic reflectivity, impedance, and amplitude variation with offset (AVO). The application of seismic monitoring for “cold flow” mapping is even more challenging. In “cold flow” heavy oil production of oil sands, we see the development of high porosity zones known as “wormholes”. These high porosity zones are much smaller than a seismic wavelength so their detection will be extremely difficult. Nevertheless, it is interesting to speculate whether time-lapse seismology has a role to play in the reservoir characterization of “cold flow” as well as in steam injection.

Introduction

One of the main applications of time-lapse seismology has been in the area of mapping steam fronts in the enhanced production of heavy oil sands. This technology has been effectively utilized by almost two decades, following the studies by Nur (1984). In Western Canada, there have been studies in the oil sands of Athabasca (Matthews, 1992), Cold Lake (Eastwood et al., 1994) and Lloydminster (AOSTRA Project Report #1296). (AOSTRA refers to the Alberta Oil Sands Technology and Research Authority.) All have shown that repeated seismic surveys can detect the decrease of seismic P-wave velocities which occur due to steam injection. In this sense, time-lapse seismology indirectly acts as a thermometer for the oil sands.

Seismic Monitoring of “Hot Flow”

Our own experience during the last two years has involved a study at Husky’s Pikes Peak field east of Lloydminster, located on the Alberta-Saskatchewan border. At Pikes Peak, various seismic attributes can be used to define steam zones including:

1. Seismic reflectivity (Matthews, 1992; Watson and Lines, 2001)
2. Seismic traveltimes (Matthews, 1992)
3 Seismic acoustical impedance (Watson and Lines, 2001)
4. AVO (Downton and Lines, 2001; Russell et al., 2001)
5. VP/VS ratio changes with temperature (Watson and Lines, 2001)

All of these seismic measurements show promise as means of detecting temperature changes in the reservoir due to steam injection. As yet, it is not clear as to which of these measures is best for seismic detection. Each has their own advantages. Figure 1 shows a differenced reflectivity section from Pikes Peak field in Saskatchewan (from Watson and Lines, 2001). Largest reflectivity differences are seen in the middle of the section just below the Waseca level.

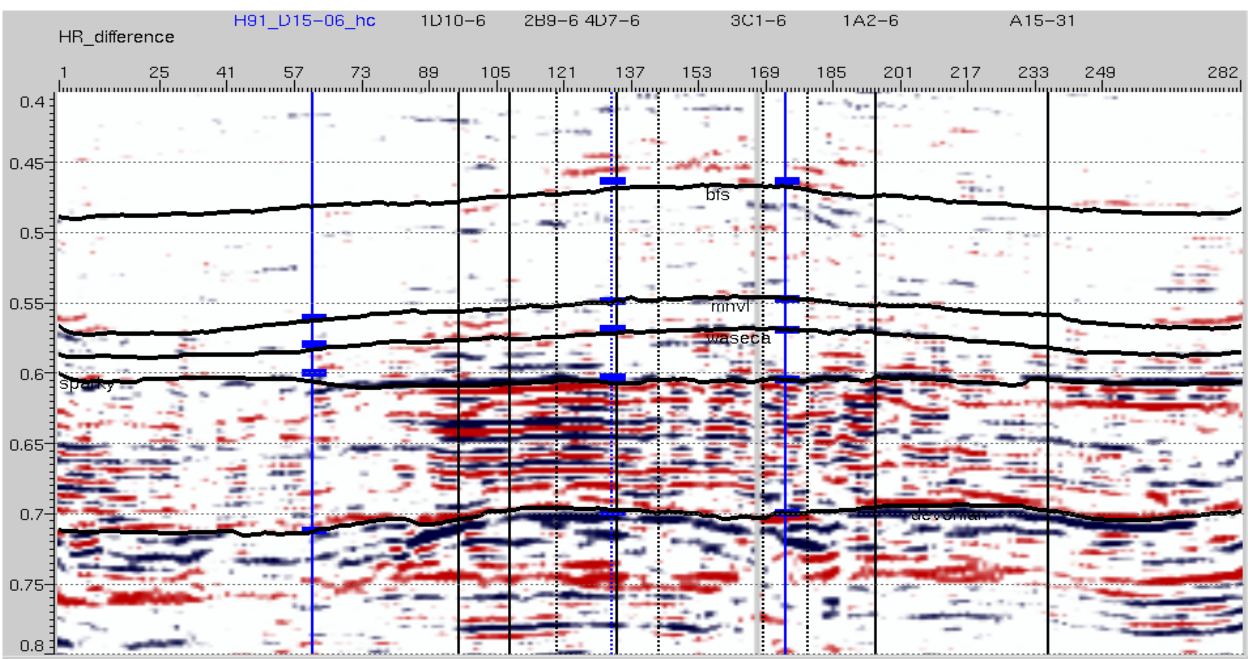

Figure 1. Difference of reflectivity sections from Watson and Lines (2001).

Emerging Interest in Seismic Monitoring of “Cold Flow” and “Wormholes”

In addition to the production of heavy oil from the steam injection in Pikes Peak field, there is production from “cold flow” heavy oil fields in the surrounding areas. In the “cold flow” production process, oil and sand are simultaneously produced in unconsolidated heavy oil reservoirs by using non-thermal extraction. A good review of cold production processes is given by Tremblay, et al. (1999).

One of the phenomena in oil sand production is the development of wormholes. Wormholes are tubes of very high porosity (over 50% in some cases) which extend out from the borehole develop during oil sand production. The high viscosity of oil sands gives the sand a higher compressive strength when dilated due to pore suction. In the lab simulations, it is seen that wormholes develop within the weaker, cleaner sands with the highest oil content. Given the higher porosity (and lower seismic velocity) of wormholes, there is the question of seismic detectability. Can wormholes be detected by seismic experiments?

Seismic detectability will undoubtedly be a function of the wormhole diameter and the seismic frequencies achievable in an experiment. In order to answer these questions, one could use modeling – both numerical and physical. If models demonstrate feasibility, then one could then try field experiments.

Conclusions and Suggestions for Future Research

The applications of time-lapse seismology to hot flow heavy oil production problems are well known and widely used in the heavy oil fields of Western Canada. Useful tools include reflectivity, traveltime, and impedance differencing, AVO and the estimation of VP/VS ratios. All attributes show some potential for mapping steam fronts in EOR. The time-lapse monitoring of cold production phenomena such as wormholes may be a much more difficult challenge. Future research will include both modeling and real data analysis to test feasibility.

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