Monitoring active steam injection through time-lapse seismic refraction surveys

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Abstract

Steam-assisted gravity drainage is an effective recovery method employed to shallow heavy oil reserves to increase the amount of recoverable oil in place. To ensure effective recovery, seismic monitoring of an active steam flood is essential in delineating the location of stimulated reserves. Typically, large and dense 4D reflection surveys are recorded to trace the motion of the steam flood, observable in terms of time shifts and amplitude difference. However, time-lapse refraction profiles can be employed to monitor the movement of an active steam flood within a reservoir in a manner similar to that of 4D reflection profiles. Through the reciprocal traveltime analysis, refraction profiles can delineate significant time-shifts within a monitor survey due to the injection of a steam flood.

Time lapse refraction profiles have significantly lower time and monetary commitments than conventional 4D reflection profiles. Refractions from the Devonian carbonates can be recorded at large offsets, thus requiring fewer sources to survey an extensive area.

This study will outline the basis for 4D refraction surveying through simple numerical modeling of a typical shallow, heavy oil reservoir.

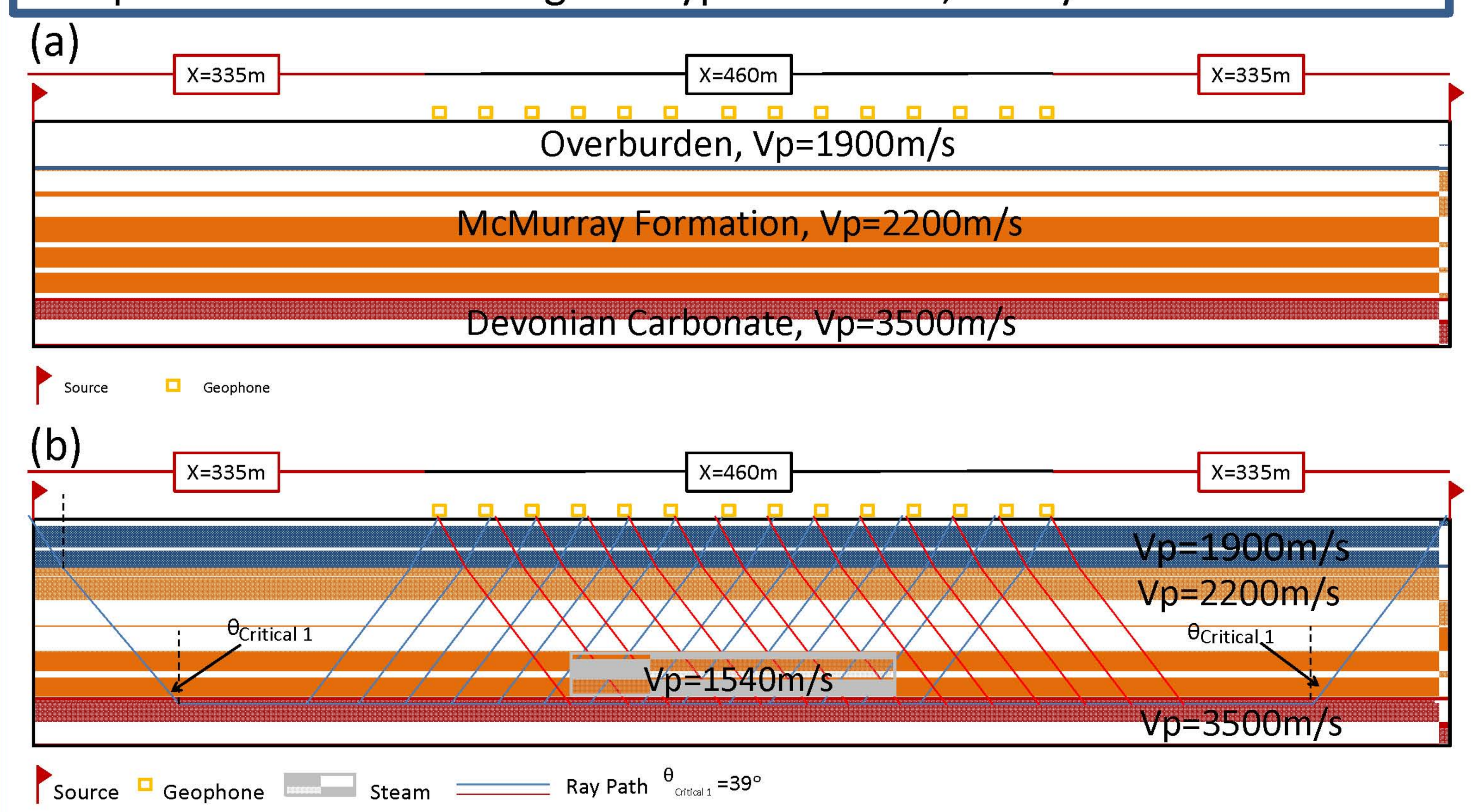

Figure 1. (a) Geological model and survey design for a single refraction line. Each source location contains one single component geophone (b) Projected forward ray path (left to right) refracting along the carbonate layer. Note that rays traveling upward through the steam zone will have a different ray path and travel time than those traveling in the non-heated McMurray Formation.

Refraction Survey Design

Modified from the design by Hansteen et al., (2010) our refraction survey consists of:

- 2 reciprocal shot points located 355m from first geophone (crossover distance for 80m deep refractor)
- 1 single component geophone at each shot point
- Recorded in radial pattern, every 11 degrees to simulate a large pad of geophones. Provides map view distribution of time-shift values.

Through the placement of a geophone at each shot point, we calculated and subtracted the time component of the downgoing wave on the source side of the array. This reduces the uncertainty of observed travel times with respect to source generated time-shifts.

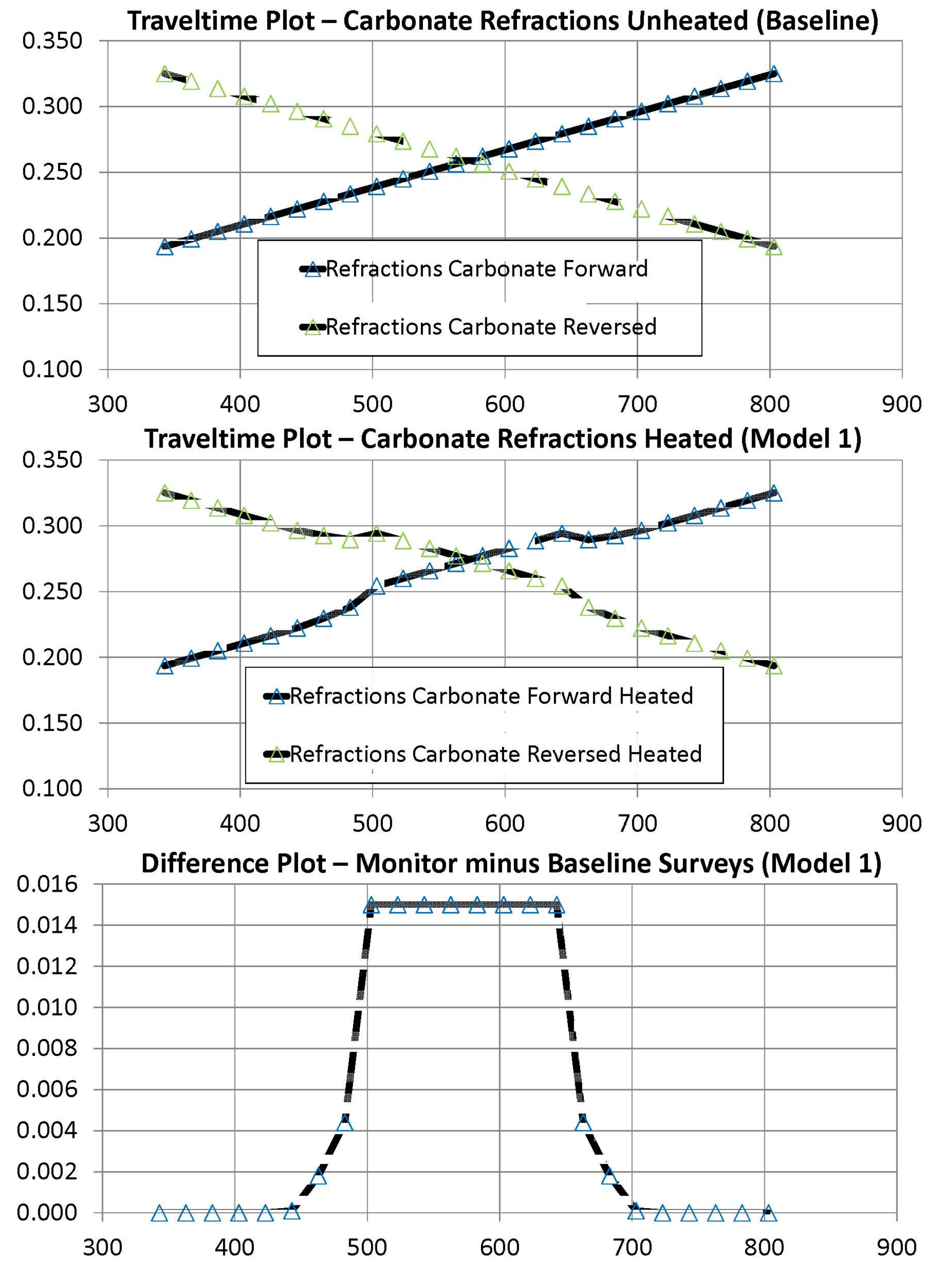

Figure 2. (a) Traveltime plot for baseline survey displaying refracted arrivals from the Devonian carbonate after the subtraction of the traveltime for the downgoing wavefield. (b) Traveltime plot after the addition of a 80m steam chamber. Time-shifts are observable on both forward and reverse profiles (c) Difference plot of the forward refraction profile, showing the traveltime difference between the unheated and heated reservoir.

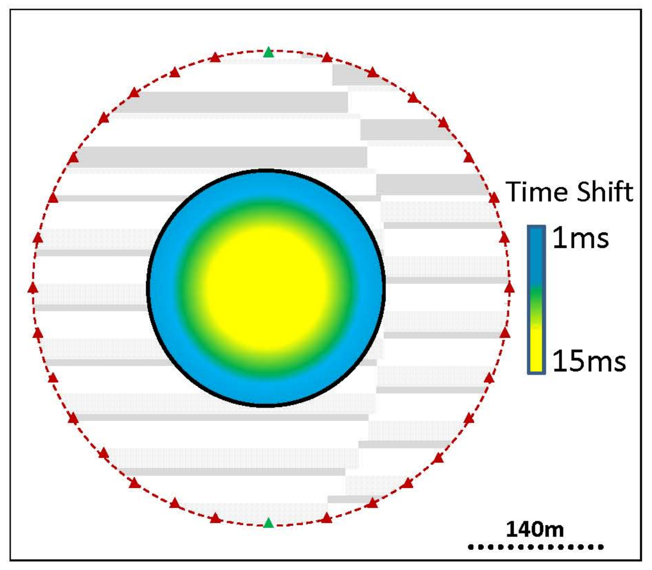

Figure 3 (a) Distribution of time-shifts due to a 60m thick, symmetrical steam chamber, 140m wide. Velocity values decrease near the edges of the steam chamber due to the reduction of heat with distance from the injection location.

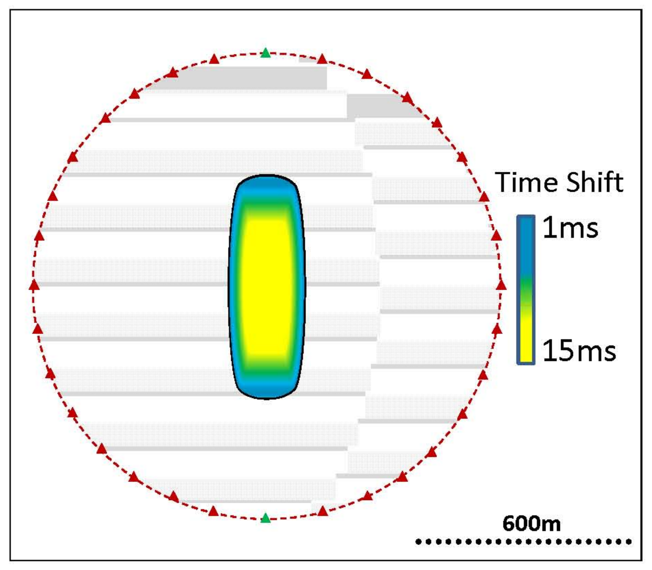

Figure 3 (b) Distribution of time-shifts due to a 60m thick asymmetrical steam chamber, representing heating through a horizontal injector well. Steam chamber is 600m long by 200m wide.

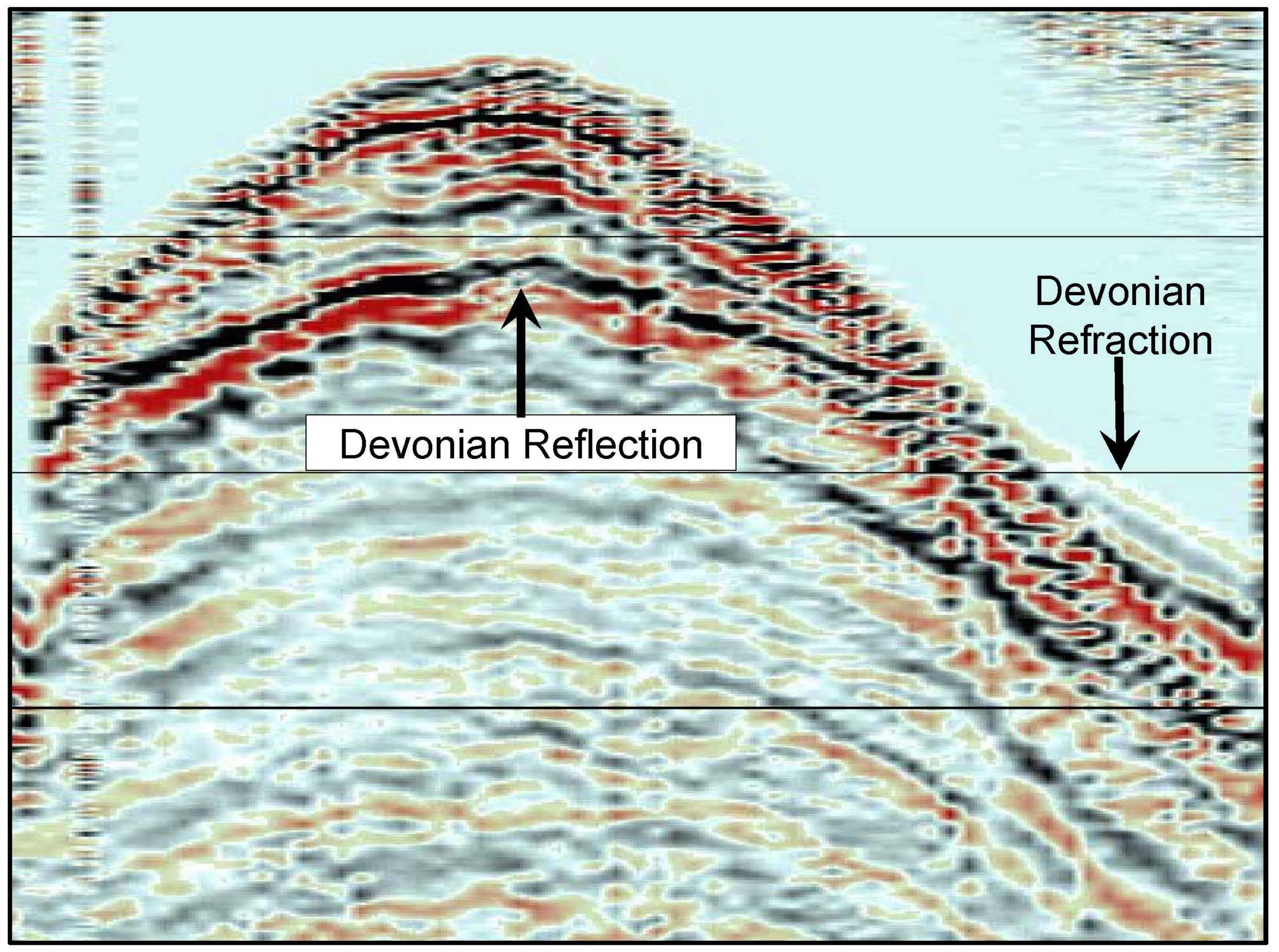

Figure 4. Raw data from a heavy oil area, Northern Alberta. Max offset = ~800m. Clear refractions from the Devonian carbonates suggest feasibility of technique on both reflection and refraction data.

Discussion

Observed traveltime changes along a modeled 2D refraction line were projected into 3D in an azimuthal distribution and plotted in map view (Figure 3).

Models 1 and 2 have the same time-shift values, but due to the difference in steam chambers dimensions, they vary in size. Model 1 represents a symmetrical steam chamber, while model 2 represents asymmetrical steam chamber growth due to a horizontal well.

Conclusion

To ensure the effective recovery of hydrocarbons via SAGD processes, seismic monitoring of an active steam front is essential in delineating the location of stimulated reserves. Seismic refraction profiles can be employed to monitor the movement of an active steam front within a reservoir through a time-lapse application.

Devonian refractions can be viewed at large offsets from a source locations, allowing for the survey extent of a single source to be significantly greater than that of reflection profiles, and hence requiring fewer sources to monitor extensive areas, ultimately reducing surveying costs.

Acknowledgements

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Reference

Hansteen, F., Wills, P., Homman, K., Jin, L., 2010, Time-lapse refraction seismic monitoring: SEG Denver Annual Meeting, 4170-4174.