

Approaches in Quantifying the Resolution of High-Resolution Time-Lapse Seismic: How Low is High?

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Summary

The results from seismic reflection surveys across steam injection chambers in heavy oils reservoirs show anomalies much smaller than the corresponding size of the Fresnel zone. Since the classical concepts of seismic resolution assumes receiver spacing in the order of the Fresnel zone diameter, high-resolution surveys with a receiver spacing of only a small fraction of the Fresnel zone diameter require special interpretation. To increase the lateral resolution special data processing steps, such as deconvolution and migration, may be applied. The effectiveness of these procedures as well as their impact on the amplitude information are investigated through a re-examination of the theoretical concepts and testing new approaches through numerical and physical modeling.

Introduction

Enhanced heavy oil production is a costly endeavor, and would benefit greatly from inexpensive, repeatable seismic methods capable of resolving the extent of changes in reservoir conditions due to production. The University of Alberta Seismic Heavy Oil Consortium (SHOC) is focused on developing such methods, and therefore addressing the question of seismic resolution is critical. In particular, we must understand the size of disturbed zone which can be imaged using high-resolution seismic reflection surveys employing closely spaced receivers. Traditional theoretical arguments suggest that at reservoir depths found in Alberta, working with relatively low frequencies, the minimum disturbed zone capable of detection would have a lateral extent of at least several 10's of meters. Yet empirical results from the Athabasca reservoir suggest that localized changes of much smaller extent can be detected (Figure 1, taken from *Schmitt, 1999*).

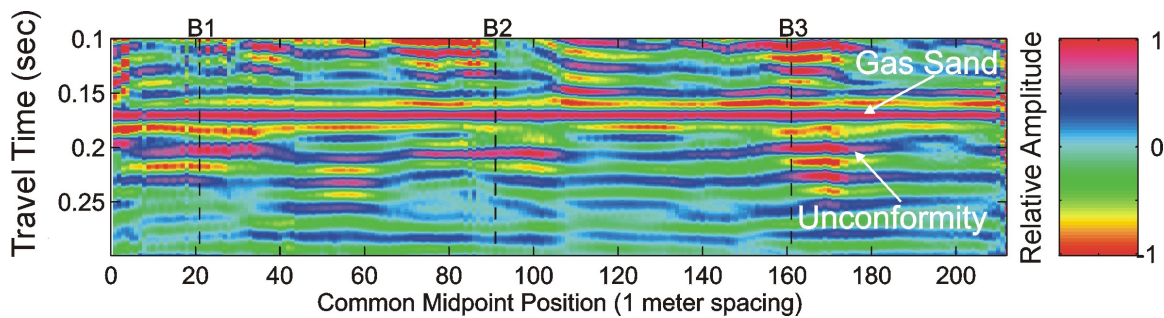


Figure 1: Reflection seismogram obtained at a steam injection site at Ft. McMurray, Alberta (indicated by the dashed lines are the position of the known injection boreholes, adapted from *Schmitt, 1999*)

The objective of the work presented here is therefore to combine theoretical, experimental, and numerical modeling work to quantify the size of anomaly that a high-resolution reflection survey can detect. The focus is not to reproduce the exact in situ materials and conditions. Rather, it is to investigate the theoretical foundations of estimates of resolution, and combine these results with experiments on controlled laboratory physical models and numerical simulations. A later objective is then to apply this understanding to the particular conditions and experimental parameters of our field surveys.

In this talk we review the traditional approach to assessing resolution, and introduce our approach, which accounts for the information provided by closely spaced receivers. Results are presented from pilot experiments using blocks of ice containing anomalies of known size and composition. Finally, numerical simulations of the wave field and the resulting seismograms are shown for typical survey geometry.

Theory and Method

Vertical Resolution

The vertical resolution of a seismic survey is determined by the frequency content and bandwidth of the applied signal. Depending on the geological settings and noise level on site the vertical resolution limit is determined by a fraction of the predominant wavelength. The Rayleigh criterion is suitable for most situations where $\frac{1}{4}$ wavelength is regarded as the limit of seismic resolution. Increasing the vertical resolution remains closely related to increasing the frequency content of the signal, either by changing the experiment parameters or by applying processing techniques such as deconvolution (e.g. *Berkhout, 1984*).

Lateral Resolution

According to *Yilmaz (1999)* the yardstick for lateral resolution is the size of the Fresnel zone. The (first order) Fresnel zone is a circular area bordered by the (two-way) rays with travel path lengths exceeding the central travel path by $\frac{1}{4}$ wavelength. The application of the Fresnel concept is bound to two assumptions, which are particularly important for surveys with small geophone spacing:

- Variation: The parameters of the medium must not vary considerably within the cross-section of the Fresnel zone.
- Intersection: The Fresnel zones corresponding to different rays must not substantially intersect each other.

Since the diameter of the Fresnel zone quickly reaches several tens of meters, both assumptions will be usually violated in surveys with receiver spacing of only a few meters and expected anomalies of only a few decameters. The detailed consequences of this violation are currently under investigation.

Reducing the Fresnel Zone Size Using Closely Spaced Receivers

Despite the Fresnel zone limits, it is possible to increase the resolution by reducing the size of the Fresnel zone. For a given dataset this can be achieved by extrapolating the measured wave field to the target horizon or by migrating the whole dataset. The resulting dimension of the Fresnel zone depends on the quality of the used velocity model required for such processing steps. Consequently the final resolution of a survey will differ with sites and the available information.

Another approach is to regard the lateral differentiation of the seismogram as representative for the difference between adjacent Fresnel zones. Although this approach contradicts assumption 2 (Intersection) for the Fresnel zone concept it would be possible with this to define a relative lateral resolution. The theoretical and numerical limitation of this approach as well as the consequences for the seismic resolution will be presented.

Physical modeling

To collect a reflection survey dataset with known parameters, physical models using anomalies embedded in blocks of bubble-free ice are made. Initially, the focus has been on zero-offset measurements using relatively large sources (on the order of the anomaly cross-section), to characterize the visibility of the anomaly under optimum conditions. A typical result is shown in Figure 2, using a block of ice 120 mm in height containing a copper cylinder of 1" diameter and approximately 50 mm in height. A 1" diameter 1 MHz P-wave transducer was used as the source, with an identical transducer immediately adjacent to the source acting as a receiver. As shown in Figure 2, the signal-to-noise ratio in this material is quite good, and the reflection from the top of the anomaly is clearly visible in the lower waveform. The reflection from the bottom of the block can be seen in both waveforms, with a slightly smaller travel time for the signal traveling through the higher velocity aluminum rod. Current work is focused on scaling the laboratory model parameters to better approximate a typical field survey, and working with arrays of sensors to include non-zero offsets.

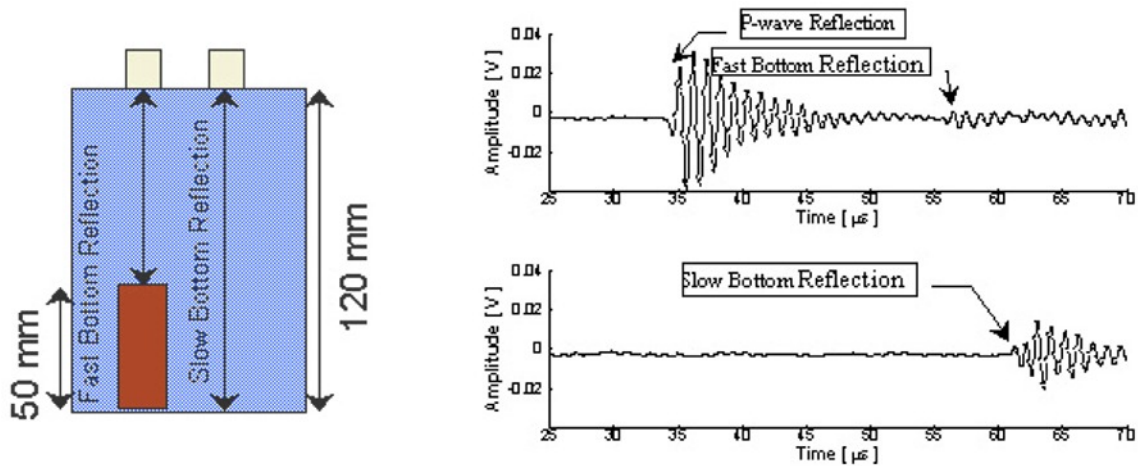


Figure 2: Schematic view of two zero-offset experiments on a block of ice and the corresponding waveforms

Numerical Modeling

From geotechnical information and reservoir models the maximum size and shape of the steam chambers can be roughly estimated. To quantify the seismic response from the steam chambers for different shotpoint-receiver geometries, numerical tests on modeled datasets are performed. Figure 3 shows the wave field over an anomaly smaller than the Fresnel zone. Although the amplitude of the reflected P-wave is small compared to the direct P-wave, it is still noticeable. The seismic response can be enhanced by concentrating the diffracted energy for this event rather than attenuating it as is the usual case through stacking. Processing steps, e.g. migration, change the amplitude information to enhance the resolution of the survey. These numerical models will show what kind of correlation exists between resolution enhancement and amplitude distortion.

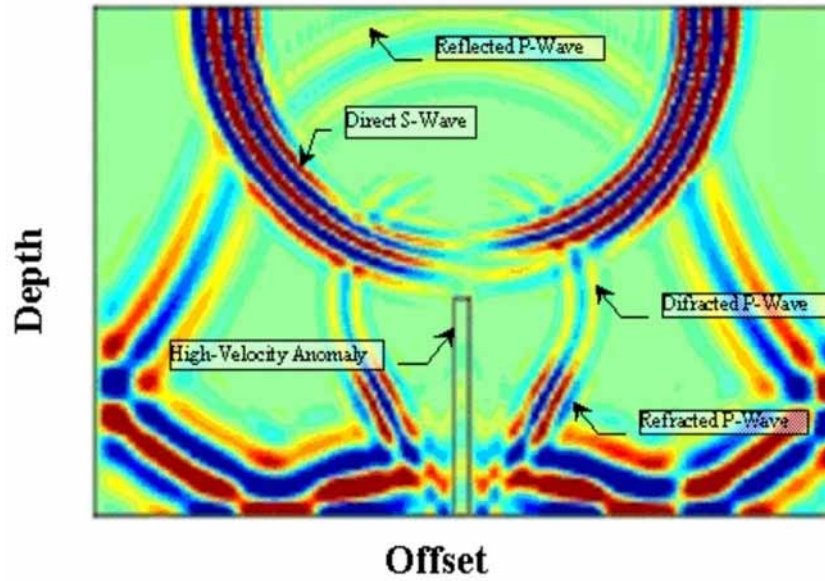


Figure 3: Numerical model of the wave field over an anomaly smaller than the Fresnel zone

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