Duplex Wave Migration for 4D Monitoring of SAGD steam chambers – Athabasca Alberta

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Summary

Duplex Wave Migration (DWM) images vertical features via a second reflection point, the first hit being off a strong mirror surface. In the HV (Horizontal first) mode, the shot to mirror path is moved to all possible positions on the mirror, moving the shot to the mirror under the target zone for migration. The DWM operator acts in a horizontal domain, and duplex reflection angles are the complement of the reflection angle on the mirror. The Duplex wave energy is very small, ~2% of the total wave field, but is separated sufficiently by the orthogonality of the horizontal DWM migration from the stronger vertical energy field. The vertical energy field is cancelled by the large number of possible DWM rays for each S-R pair, and by the differing DWM ray path geometry. This new type of pre-stack depth migration is used to directly image near vertical sides of the SAGD chamber, and potential zones within the steam chamber. Further, the DWM imaging can selectively illuminate S-R pairs from one side – 180° half space apertures. This eliminates duplicate images from the Left and Right apertures, and confusing superposition of opposing polarities.

Introduction

The DWM migration method was applied to a SAGD project in the Athabasca tar sands using the same conventional Before and After 3D survey, conducted after 16 months of steaming. This was a first-time application. The Time to Depth model is derived from the 3D vertical processing, but no additional data acquisition is required, just the additional DWM processing workflow.

Theory and/or Method

Figure 1: Schematic of Aperture and Offset definitions. Note: Aperture has additional space, since location of the vertical feature is unknown, and is not in the Depth model. Dip cases separate easily by offset, and are uniquely different from the vertical seismic, since DWM image points are always outside of the S-R pairs.

Figure 2: Schematic showing multiple possible ray paths from mirror for a single S-R pair. Green trace is a physically rotated seismic trace containing duplex wave energy. The vertical energy is cancelled by the numerous mispositioned responses, while in phase duplex wave energy adds within the Fresnel zone.
Figure 3: **Front side** with “Left looking” illumination - Black events in Figure 5. Exterior image points are in the correct position. Vertical walls case will reflect parallel. Dip case is sensitive to aperture loss/gain at ±2 x Dip angle.

Figure 4: **Back side** internal reflections are limited by total internal reflection. Path through the slow SAGD heated bitumen is not at the correct velocity, and additional two-way path will cause image points to be placed behind and slightly defocused — causing wider red events in Figure 5.

Figure 5: Right and Left illuminations, and full 360° illumination. The full 360° azimuthal aperture does not improve imaging, contrary to the higher (4x) fold. This results from the opposing Right and Left images with opposite polarities destructively interfering. Broader events caused by the slower velocity (warm colours) and the two-way path through steam chambers. Required to calibrate the apparent thickness — i.e. Thickness = \( D_{app} \times \frac{V_o}{TWD \ F} x \frac{1}{1} = 36m \times \frac{1650}{2450} \times \frac{1}{1} = 11.5m \)

Two events. Front and Back sides, within 11m gives excellent resolution of 5 to 6m. So, the Backside defocusing is a minor loss, when compared to the vertical PSTM resolution of 4 – 5m. Two-way distance Factor (TWD F) is derived from modelling the DWM ray path.
Presentation will show the following results:

1) A clear front side reflection, and a surprising back side reflection, resulting in 5 - 6m resolution - very close to the 4 - 5m vertical resolution. So, seismic energy must pass through the steam chamber, allowing more detailed information from inside of the steam chamber to be measured.

2) Induced velocities in the steam chamber must be much lower 1200m/s to 1650m/s to bend image rays to near horizontal, reflected off the backside and re-emerging at the front side – as a coherent wave.

3) Comparing the Left and Right illuminations and the Front and Back side reflections – 4 values – allows for a possible steam attenuation signature to be analyzed.

4) DWM response can be scaled by various parametric relations to view pseudo properties: temperature, viscosity, shale content / permeability and water saturation. The gas attenuation inference could be very useful here.

**Production prediction**

Production versus Total Amplitude response per well
Left illumination: Front + Back

Figure 6: Actual bitumen production versus DWM Amplitude calibration

Attenuation analysis with the two Right and Left illuminations (4 picks) by comparing RC transmission loss corrected curves – red curves in lower 2 panels of Figure 9.

Figure 7: Corrected Front & Back reflections compared to CMG STARS image integration.

Figure 8: Lateral picks on 1m sub sampling with interpolation. Migration bins are 1m x 5m x 5m. Note: Red reflections are from the inside surface.

Figure 9: Front & Back reflections paired to analyze attenuation for presence of gas/steam.

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Conclusions:

The DWM seismic response has sufficient amplitude fidelity to preserve rock properties and other potential attributes, some still to be discovered. DWM geometric advantage allows rays to penetrate the SAGD Chamber without total internal reflection restricting returning rays. The improved delineation of the SAGD melt zone boundaries is used to identify over and under developed areas, which enables reservoir engineers to target on-going steaming efforts more efficiently.

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References:

Duplex Wave Migration and Corner Reflector Approximation
N. Marmalevsky* (Tatrale Group), A. Kostyukevych (Tatrale Group) & G. Dubrova (Tatrale Group) - EAGE 2013

Fracture prediction verified by well results and forward modeling
Brian H. Link* Tetrale Technologies Inc, Calgary, Canada, Inga Y. Khromova Lukoil Moscow Russia, Alexander S. Kostyukevych Tesseral Technologies Inc, Calgary, Canada - CSEG Recovery 2011

Duplex Wave Migration for Coal-bed Methane Prediction
N. Marmalevsky* (Ukrainian State Geological Prospecting Institute), A. Antsiferov (UkrNIMI), Z. Gornyak (Ukrainian State Geological Prospecting Institute), I. Khromova (LUKOIL), A. Kostyukevych (Tesseral Technologies Inc) & M. Tirkel (UkrNIMI) - EAGE 2009

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