geoconvention
Virtual Event
September 21-23
2020
CSPG • CSEG • CWLS • GAC • MAC • IAH

4-D Time Lapse Full Waveform Inversion Case Study for SAGD Steam Chamber Imaging

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Summary

During Steam Assisted Gravity Drainage (SAGD) operations, 4-D time lapse seismic is widely used to monitor the steam chamber growth (Lumley, 2001; Maharramov et al., 2016). It may be possible to pick a top and/or base steam chamber event on the reflection stack data. Standard 4-D seismic attributes such as travel time delay and RMS amplitude anomaly are typically used to qualitatively interpret the thickness of the steam chamber and location of the steam front. However, these attributes have difficulties to determine the internal geometry of the steam chamber. The inverted velocity difference from the Full Waveform Inversion (FWI), which runs on the raw shot gathers with the possibility of a short 4-D turnaround time, provides an efficient way for the quantitative estimation of steam chamber geometry, which can result in more timely production decisions. An FWI process was applied to a monitor and baseline seismic dataset acquired on the Sunrise SAGD project near Fort McMurray, Alberta.

Theory / Method / Workflow

Full Waveform Inversion (FWI) initially emerged as an advanced tool for complex velocity model building (Crase et al., 1990; Kotsi and Malcolm, 2017; Warner and Guasch, 2016). The FWI-derived velocity model coupled with advanced imaging algorithms such as pre-stack depth migration (PSDM) and reverse time migration (RTM) can dramatically improve the subsurface imaging from extremely complicated structures that exhibit abrupt vertical and lateral velocity changes (Zhang and Zhang, 2011; Zhang and Huang, 2013). The oil and gas industry has seen very successful applications of FWI in different geologic settings such as the complex subsalt targets in the Gulf of Mexico.

FWI is driven by minimization of the data residual between the real raw shot gathers and the simulated shot gathers by an iterative process that results in a high-resolution velocity model (Figure 1). Two key requirements in the FWI method are efficient forward modelling and local differential computation, which are two major computational costs in the FWI process.

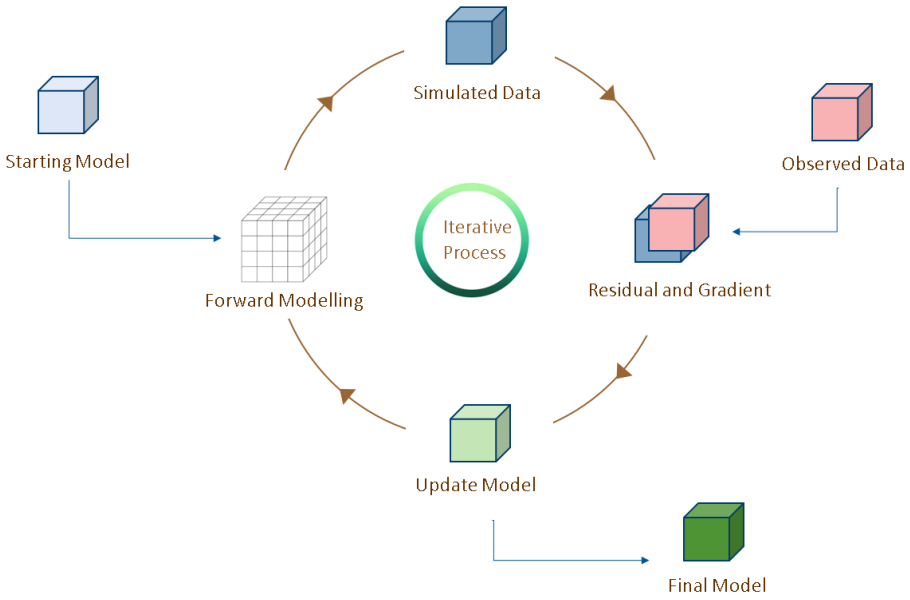

Figure 1: Workflow of full waveform inversion (FWI)

Results

The two outputs of 4D time-lapse FWI are the velocity difference volume between the baseline and monitor surveys and the PSDM volume which can provide improved imaging. Velocity changes are a function of saturation, temperature and pressure, with the greatest velocity change associated with a gas phase. As a result, the velocity difference between the baseline and the monitor surveys can be used for the direct interpretation of the developed steam chamber. The preliminary analysis of the inverted 4D time-lapse FWI velocity difference shows a very encouraging image of the steam chamber inside the reservoir which is crucial for the understanding the heterogeneity of the reservoir and future development plans. The inverted FWI velocity difference was validated with vertical well temperature logs, top/base steam chamber events from the reflection seismic volume, the time delay map and the surface heave map.

The improved seismic imaging of the steam chamber on the PSDM section compared with the depth converted PSTM image using the traditional velocity model is shown in Figure 2. On the

upper section, the geometry of steam chamber is not focused, and the steam chamber geometry is less clear. On the lower section, the base of steam chamber is more focused and clearer.

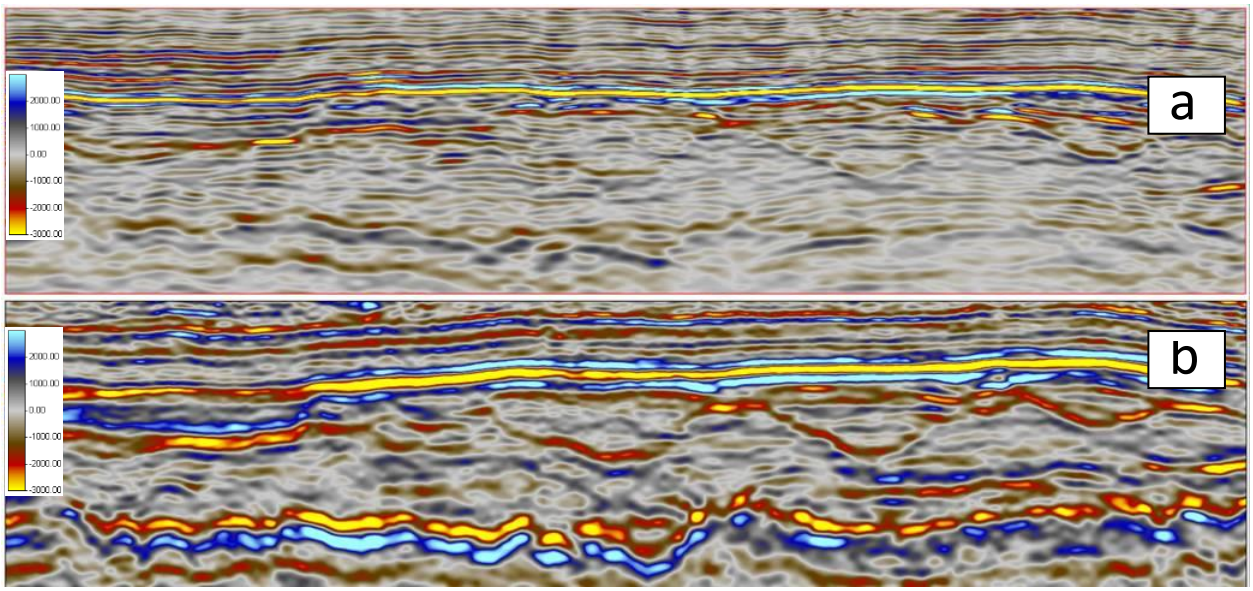

Figure 2. PSTM image using the traditional velocity model (a) and the FWI derived PSDM volume (b).

A 3-D perspective image illustrating the velocity difference volume with horizontal and vertical slices over producing SAGD pads is shown in Figure 3.

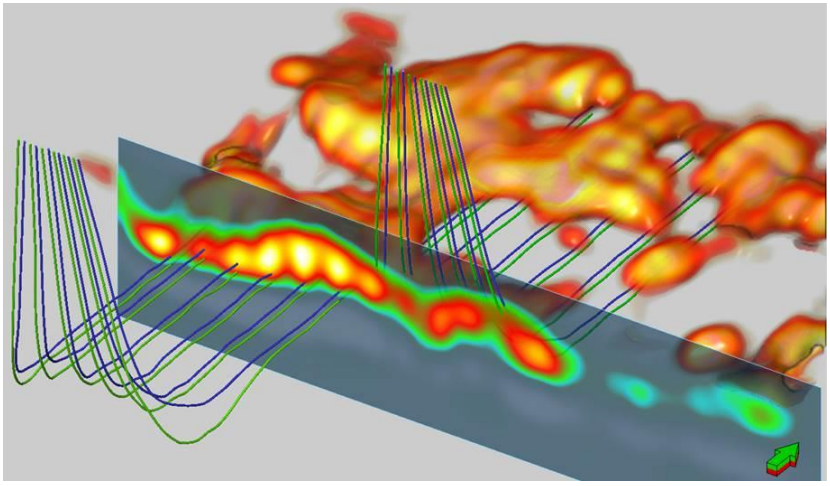

Figure 3. A 3-D perspective image of a velocity difference volume with horizontal wells.

Conclusions

We adapted the FWI methodology for an innovative application that jointly inverts the time-lapse datasets for the SAGD steam chamber interpretation. Compared with traditional time-lapse inversions, the new time-lapse FWI methodology demonstrated some advantages and improvements. It can deliver the velocity difference volume directly from the raw shot gathers with minor pre-processing of the seismic gathers, which results in a reduced turnaround time to implement production decisions. The PSDM volume produced with the FWI derived velocity model shows a dramatic improvement in imaging.

Acknowledgements

The authors would like to thank their respective companies for permission to publish.

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