SAGD Well Planning Using Stochastic Seismic Inversion

Franck Delbecq*
Hampson-Russell Reservoir & Services, CGGVeritas, Calgary, Canada
franck.delbecq@cggveritas.com

and

Rémi Moyen
Hampson-Russell Reservoir & Services, CGGVeritas, Crawley, United Kingdom

Summary

The complexity of heavy oil geology in SAGD projects, especially the presence of thin shale barriers that are beyond the resolution of traditional seismic data and deterministic seismic inversion; makes the integration of seismic data with geological well data challenging. Stochastic inversion represents an improvement over deterministic inversion as it allows the generation of a large number of equally probable high-frequency models that can be used for uncertainty analysis.

It is possible to take advantage of the multiplicity of high frequency results from stochastic inversion in order to better characterize the reservoir, and in particular to identify the thick continuous basal sands required for optimal SAGD well positioning. The workflow described here produces outputs such as the probability of continuous bitumen, or the uncertainty in the position or thickness of the reservoir sands. These can be used to optimize potential well locations, from which it is also possible to compute the probable producible bitumen volume. This approach not only provides higher precision when integrating the seismic and the well data, but also quantifies the uncertainties associated with the reservoir characterization process.

Introduction

Seismic data is often integrated into geological models using deterministic seismic inversion that produces a single distribution of elastic properties that are used to build a litho-facies or petrophysical model of the reservoir. However, the seismic information content is band limited thus thin shale layers which can have a very strong impact on production in heavy oil reservoirs may not be resolved. Stochastic inversion techniques are a way to address this problem, by generating a family of possible elastic property models, all honouring the seismic information, with a frequency content higher than the seismic and a better match with elastic well logs.

This proposed workflow uses the results of such a stochastic inversion in order to better characterize continuous bitumen, and to optimise the placement of SAGD wells. The key advantages of this workflow are the ability to merge seismic and well data to characterize very thin layers, as well as the probabilistic approach, generating probability cubes and allowing for a quantification of the uncertainty.
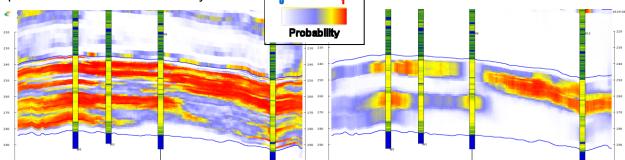

Figure 1: Bitumen probability (left) and thick continuous bitumen probability (right) in a random section (wells coloured by density, sands in yellow, shales in green and carbonates in blue)

Stochastic Inversion

The methodology was tested on seismic data acquired over a heavy oil field located in Alberta. The survey size is 1.25 sq miles including 16 delineation wells. The seismic data has frequencies up to 200 Hz and 4 angle stacks are available, ranging from 6 to 28 degrees. Statistical wavelets were extracted from the seismic and the wells. The target is about 40m thick and contains bitumen sand, gas sand, IHS, shale layers and calcite streaks.

A stochastic seismic elastic inversion was performed using a Bayesian framework based on a linearised AVA model (Buland & Omre 2003, Escobar *et al.* 2006) to calculate a joint posterior distribution for P- and S-Impedances, constrained by seismic amplitudes measured on a number of input angle stacks. This posterior distribution is sampled sequentially and repeatedly to generate in the order of 250 different high-frequency 3D realizations of elastic properties. The stochastic inversion is performed in a fine-scale stratigraphic grid defined in the time domain, with horizontal sampling fixed by the seismic bin size and vertical columns of cells with variable thickness, typically much smaller than the seismic resolution.

The inversion is directly constrained by the seismic data and also by the wells, allowing for better control of the higher frequencies. Moreover, lateral continuity is imposed through vertical and horizontal variograms that are extracted from the well data. Among the 16 wells, 12 were used to directly constrain the inversion. The remaining ones were used to validate the inversion results.

A simple depth conversion was applied, using an average velocity field calibrated with the wells.

Facies Classification and Characterization of Basal Sands

1- Facies classification & probability of bitumen

The analysis of well logs found three main facies, according to their lithology and fluid content. The reservoir is made principally of clean sands that can be divided between bitumen-filled, gas-filled, and shales. Inversion results are consistent with well logs, and show that a good facies discrimination is achieved using a well-derived P-Impedance versus S-Impedance cross-plot. By counting the number of realizations of elastic properties classified into each facies in each cell, a facies probability cube can be computed, as shown in Figure 1 (left) and the uncertainty in seismic lithology prediction from the stochastic inversion can be estimated.

2- Continuous bitumen detection

For optimum SAGD production, it is necessary to identify sand bodies that are suitable for pad placement, i.e. thick basal continuous bitumen sands (Garner *& al.* 2005). These sands are identified on each realization, using simple geometric criteria such as the minimum lateral extent of shales that would be considered a barrier, or the minimum thickness of clean sands required (8-10 m). It is important to note that only statistical parameters extracted from all realizations will be used afterwards and therefore the approximations in the characterization methods are expected to be averaged out. As for the facies, the realizations can be combined to produce a cube of probability of thick sands (Figure 1, right).

3- Basal sands characterization

Once the thick basal continuous bitumen sands are identified on each realization, several global indicators are computed:

- The first one is a map showing the proportion of realizations for each bin in which such sand exists, which is an estimate of the probability of basal sands (Figure 2, left).

- The second indicator is the statistical distribution of the thickness of the basal sands: the median thickness for each location (Figure 2, right) gives an indication of the thickness that can be expected, whereas the P10 and P90 provide information on the uncertainty.

- A third indicator is a thickness map of the first shale layer above the basal sands, with its uncertainty.
- Other indicators are pessimistic, median and optimistic (P10, P50, P90) cases of the position of the top and bottom of the basal sands (Figure 3, left).
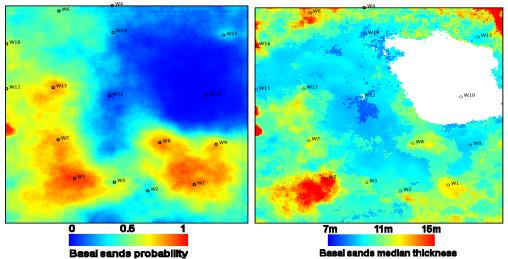

Figure 2: Map of probability of sands (left), map of P50 (median) of sands thickness (right). The white area has no basal sands.

Well Planning

In order to illustrate the benefits of this technique, the position of a simple set of SAGD wells was planned, omitting engineering constraints. These wells were also designed with the objective to do connectivity analysis and to determine meaningful scenarios in the subsequent section.

- Using the outputs from the basal sands characterization, a simple pad of optimally located horizontal wells 500 m long and separated by roughly 100 m was designed.
- The map of probability of basal sands (Figure 2, left) indicated that the pad should be placed in the SW corner, or maybe in the SE.
- The map of median thickness of the basal sands (Figure 2, right) indicated that the thickest sands are in the SW, and the similar map of the thickness of the barrier immediately above the sands also shows the thinnest barrier (i.e. the most likely to be broken through by steam injection) in the same area, confirming that this is the best location for a new pad.
- The top and bottom (P10, P50, P90) surfaces were used to optimally place the pads in depth, so that the producers are between the P50 and P90 of the base (i.e. almost always inside the sands, toward its base). The injectors are placed 5m above and so that they do not cross the P50 of the top.
- Finally, the proposed design, shown on Figure 3 (left) was validated in a 3D model displaying various confidence intervals on the position of the basal sands top and base.

Connectivity and Ranking

Although this proposed pad is simplified, it can nonetheless be used as a starting point to assess the vertical connectivity and to rank the realizations using a criterion relevant to the production scheme. As a first approximation, the volume of bitumen sand that can be swept from a given producer well can be estimated by computing a simple steam chamber as an inverted triangle around the wellbore (Butler 1991). The producible volume is computed for each

individual realization. The probability of producible bitumen (Figure 3, right) can be computed. It is then easy to test different well locations and find better locations for production. In this example higher probability was found to be on the right of the section which shows higher confidence of good production.
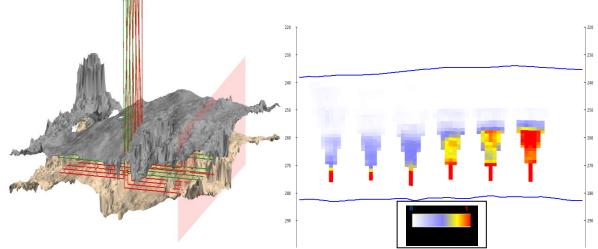

Figure 3: Left, proposed pads (producers in red, injector in green) between the median (P50) position of the top and base of the basal sands. Right, section going through the south pad (along the highlighted plane) after connectivity analysis.

This ranking can be shown as being very different from a ranking based on the total volume of bitumen sands in each realization (Moyen & Doyen 2009). As the former is likely much closer to real production, it is therefore also more useful (McLennan & Deutsch 2005). This ranking can be used to select a few individual realizations, typically a pessimistic, median and optimistic case (P10, P50 and P90) on which a more complete and realistic production and flow model will be built.

Conclusions

This workflow makes better use of seismic data in the characterization of heavy oil fields, systematically using probabilities in order to assess the uncertainties of each output.

It also allows integration with geomodeling and moves seismic towards reservoir engineering by looking at potential drainage volumes, flow barriers and pad placement.

Acknowledgements

The authors thank an anonymous client for the use of their data, as well as CGGVeritas and especially Dave Gray for the fruitful discussions.

References

Buland, A. and Omre, H., 2003, Bayesian Linearized AVO Inversion: Geophysics, 68 (1), 185-198.

Butler, R. M., 1991, Thermal Recovery of Oil and Bitumen, Englewood Cliffs, N.J.: Prentice Hall.

Escobar, I., Williamson, P., Cherrett, A., Doyen, P. M., Bornard, R., Moyen, R., 2006, Fast Geostatistical Stochastic Inversion in a Stratigraphic Grid: SEG 76th Annual Meeting.

Garner, D., T. J. Wheeler, E. Mus and J.-F. Richy, 2005, Uncertainty Quantification and Ranking for SAGD Well Pair Placement in the McMurray Oilsands: Canada: AAPG International Convention, Paris, Sept 11-14.

McLennan, J. A. and Deutsch, C. V., 2005, Ranking Geostatistical Realizations by Measures of Connectivity: SPE International Thermal Operations and Heavy Oil Symposium, SPE/PS-CIM/CHOA 98168.

Moyen, R. and Doyen, P. M., 2009, Reservoir Connectivity Uncertainty from Stochastic Seismic Inversion: SEG 79th Annual Meeting.