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Realistic DFN Modelling Using 3D 3C Seismic Data for the Marcellus Shale with Application to Engineering Studies

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SUMMARY

The development of resource plays is moving on from drilling on a regular grid; but it is not sufficient to ‘simply’ identify a sweetspot in a resource play. It is also necessary to understand connectivity and compartmentalisation, this may be achieved through the development of a realistic fractured reservoir model. Seismic data volumes, inversion studies and rock physics provide a wealth of information covering reservoir intervals. Co-rendering of the data volumes leads to a more easily interpretable image of the subsurface and a better understanding of the reservoir. This paper discusses the construction of a realistic DFN model that was built using inputs derived from a 3D multi-component seismic dataset, seismic attributes, anisotropy information, seismic inversion results and well data. As model incorporates the seismic data deterministically the DFN can be used to guide well placement and planning, predict inter-well connectivity and can be used to forward model completions in terms of fracture generation or reactivation and micro-seismic event generation.
Introduction

The development of resource plays is moving on from drilling on a regular grid; but it is not sufficient to ‘simply’ identify a sweetspot in a resource play. It is also necessary to understand connectivity and compartmentalisation, this may be achieved through the development of a realistic fractured reservoir model. Seismic data volumes, inversion studies and rock physics provide a wealth of information covering reservoir intervals. Co-rendering of the data volumes leads to a more easily interpretable image of the subsurface and a better understanding of the reservoir. However, enhanced understanding of the reservoir can be achieved by constructing a discrete fracture network (DFN) model that address these and other issues.

This paper discusses the construction of a realistic DFN model that was built using inputs derived from a 3D multi-component seismic dataset, seismic attributes, anisotropy information, seismic inversion results and well data. The advantages of building a DFN are many and include; understanding connectivity, compartmentalisation and drainage volumes. In this case, as the model incorporates the seismic data deterministically, the DFN can be used to guide well placement and planning, predict inter-well connectivity and can be used to forward model completions in terms of fracture creation or reactivation and micro-seismic event generation.

Case Study

A DFN model has been constructed for the Marcellus Shale interval (between the Tully and Onondaga Limestones) covering a 3D multi-component survey area that was acquired in Western Pennsylvania over the Marcellus Shale; the Allegheny Survey. One of the perceived issues with DFN modelling is that fractures tend to be too uniform in length and spatial distribution, although the stochastic generation process should avoid this issue. The challenge in DFN model construction can be summarised as two main issues:

1. Paucity of data or the difficulty in obtaining suitable data on small scale faulting and fracturing and
2. Constructing a realistic model.

The construction of this realistic DFN model is differentiated from other models by using deterministic inputs derived from seismic data and well log information. The data sources included:

- Seismic volumes covering an area of 85 square miles.
- Azimuthal velocity analysis of PP datasets, the AZIM process or for PS datasets the SEAC workflows (measuring shear wave splitting and anisotropy).
- Seismic Interpretation
- Seismic attributes
- Wireline data
- Seismic Inversion results

Time slices through a 3D seismic volume are shown in Figure 1; co-rendered Fault Probability and amplitude (left) and dip illuminated structure (right). The objective of the modelling was to generate a model that closely represented the faulting and fault geometries seen in the Allegheny structure map shown in Figure 1 and to include additional fracturing that is below seismic resolution.

The construction of the DFN follows a simple workflow that begins with a seismic consistent grid and geocellular model. The layer geometries are defined by the interpretation and mapping of seismic
horizons and fault segments which are then added to the geo-cellular model. The next step in the process is to add the small scale faulting and fracturing that is below the resolution of seismic data. This is often a stochastic process where the input data may be derived from sources including: image log data, well logs, core and analogue data.

**Figure 1** Co-rendered seismic amplitude and fault probability (left) Dip illumination of the Allegheny Structure map on the Onondaga surface level showing the locations of faults (right).

In this case the small scale faults and fractures were generated by correlating the stochastic fracture generation process with a number of different deterministic data sets and attributes derived from the seismic data. This included fault probability data, which were used to generate one of the fracture sets in the DFN model. The fault probability data were derived in Transform 3.3.1 by running a geometric filtering technique on an incoherency volume to search for the most fault-like features. From Figure 1 it is clear that numerous large faults and fracture sets can be seen in the data and these are shown by the dark grey/black linear features. Also seen in the figure are smaller structural features which are observed as light grey linear features. The fracture sets that were generated based on the fault probability data are shown in Figure 2 (right).

**Figure 2** Fault Probability map at the Onondaga level showing the locations of probable faults (left) and modelled fracture systems based on fault probability data (right).
The two images in Figure 2 show a high degree of similarity and also show that the distribution of features is not uniform spatially. The azimuthal velocity analysis (AZIM) provides information on the magnitudes of $V_{p_{fast}}$ and $V_{p_{slow}}$ along with their directions. These data are used to provide fracture information and generate anisotropy data which is utilised as another deterministic input to generate a second fracture set. These fracture sets are shown in Figure 3 (left) along with larger deterministic faults. A view of the DFN model showing all fracture sets is shown in Figure 3 (right). The data used to define the fracture geometries in terms of dip were obtained from published literature (Engelder, et. al, 2009).

Figure 3 Fracture set based on anisotropy information derived from the PP AZIM analysis (left) and all fracture sets (right), fault probability, anisotropy and deterministic faults and fractures.

An enlarged view to the south of the model (Figure 4) shows the locations of two hypothetical laterals. Prior to any forward modelling it may be predicted that communication would occur between them as they would be drilled through two fault zones.

Figure 4 Enlarged section of the DFN model showing two hypothetical; laterals; deterministic faults and fractures based on fault probability are shown.

The PP and PS seismic data were inverted providing elastic properties including Lambda Rho, Mu Rho, Young’s Modulus and Poisson’s Ratio. These data, along with the principal stress magnitudes; stress
directions (Engelder, et. al, 2009) and estimates of local stress directions were loaded into the model. The populated DFN model was used to forward model the hydraulic fracture stimulation process and micro-seismic event generation (Figure 5). From Figure 5 it can be seen that greater number of micro-seismic events are likely to be seen in areas with higher fracture densities (towards the toe and heel of the wells; right and left respectively) suggesting reactivation of pre-existing structures. It also suggests that fracturing would occur along the well paths in the central sections. This suggests that the fracture density would be increased by the hydro-fracturing. The modelling suggested that communication between the wells and along the wells from one stage to another would be observed.

Figure 5 Enlarged section of the DFN model showing stimulated/created fractures (multi-coloured) and one of the modelled fracture sets based on fault probability (purple).

Conclusions

This case study demonstrates that realistic DFN models can be generated for resource plays that show variability of fracture size and spacing. The DFN model was constructed based on information derived from 3D multi-component seismic data, including seismic horizons; seismic attribute, interpreted faults and seismic scale faults that were extracted and mapped from fault probability and anisotropy data that were derived from azimuthal velocity analysis of the seismic data. It was populated with data derived from joint and simultaneous seismic inversion. The resulting model was used to forward model hydraulic fracture completions of the two hypothetical wells. The results of the modelling illustrates that interpretations and predictions can be made that could impact drilling and completion strategies and designs with the accompanying financial implications.

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References