

Using Discrete Hydraulic Fracture Simulations to Inform Stimulation Optimization in the Montney

Steve Rogers, Mark Cottrell: Golder Associates Ltd

Randy Hughes, Chelsea Squires: Painted Pony Energy Ltd

Introduction

In recent operations in the Montney, Painted Pony observed very different responses to stimulation between the Upper and Lower Montney wells in terms of production rates and their response to completion intensity, observed microseismic behavior and reactivation potential of larger faults, Fig 1. In particular, fault plane solutions from the processing of microseismic data showed that the primary movement of hydraulically induced and natural fractures in the Upper wells was NE-SW (SHmax parallel) whereas in the Lower wells it was typically NW-SE (i.e. SHmax perpendicular). Clearly the stimulation was behaving in a drastically different way in each of the two layers, with the role of natural structures (a potential fabric of natural fractures/joints) being thought critical to this response, but testing was required to assess this with certainty.

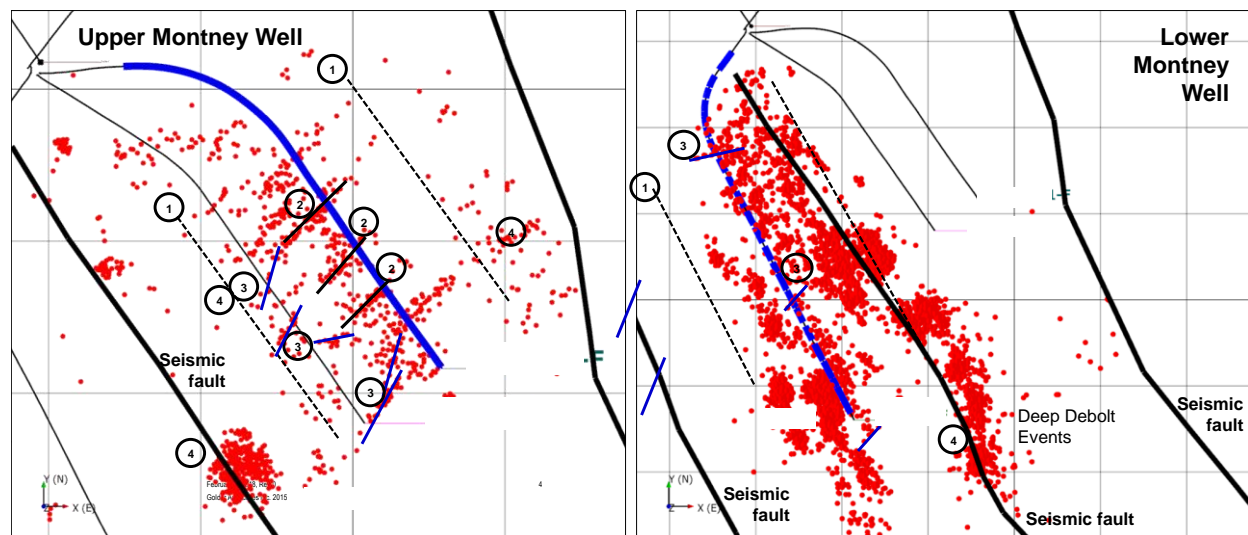


Fig. 1. Observed microseismic response on a typical Upper and Lower Montney well showing very different stimulation responses. The numbers relate to criteria used for comparing simulation matches later with (1) HF length extent (2) asymmetry (i.e. not symmetrical) (3) notable variation from SHmax trend & (4) evidence of NW-SE structure role. Seismic faults shown at the top Debolt

A Discrete Fracture Network (DFN) based hydraulic fracture analysis was identified as the best way to answer this question, using the FracMan® code. FracMan is a DFN based hydraulic simulator using a novel mass balance approach to frac simulation (Dershowitz et al 2010). This allows the simulation of hydraulic fracture growth, through a fabric of natural structures, with the reproduction of microseismicity as a key calibration goal. With uncertainty in the subsurface structural fabric, number of unique simulations were required and FracMan's high-speed formulation provided an ideal solution.

Data Analysis & Conceptual Model Development

The main data available from the pad in question was DFIT data, elastic log data, the microseismic (MS) event catalogue from each well and stage, fault plane solutions for a subset of the MS events and seismic scale fault interpretation, Fig 2.

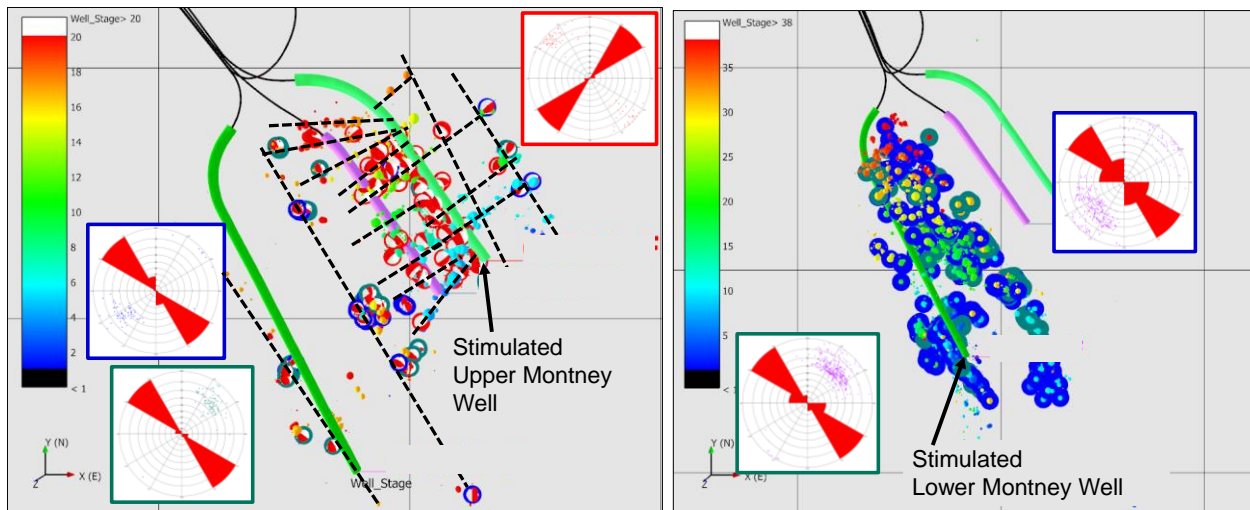


Fig. 2. Fault plane solution results for Upper (left) and Lower (right) wells showing the strike of interpreted shear planes. The Upper well is predominately NE-SW with minor orthogonal movement whereas the Lower well is completely NW-SE. The stimulated wells are indicated. The rose diagram's margins are coloured according to the dip direction of the fault plane solutions and the same colour is used on the microseismic points

These data and observations were developed into a conceptual fracture model which served as the basis for developing a Discrete Fracture Network (DFN) model of the Upper and Lower Montney fracture systems. A fit-for-purpose geomechanical analysis was carried out to develop a simple geomechanical earth model of stresses and elastic properties in the area of the pad. This showed the stress regime to be a hybrid strike slip-reverse faulting system with S_v and S_{Hmin} magnitudes relatively close to each other. This geomechanical description was combined with the DFN model as the basis for simulating hydraulic fracture stimulation in wells on the pad. The key aspects of the two layers were:

- The Upper Montney appears to comprise both NE-SW and NW-SE unit scale jointing, with only weak or no connection to deeper and larger fault structures extending down to the Debolt.
- The Lower Montney appears to be far less intra-unit connected, primarily showing evidence for both long unit-bound NW-SE joints as well as larger fault structures extending downward into the underlying Debolt. In the absence of a clear insight into the nature of the long NW-SE fault related unit-bound joints we have used the term “mega joints” to capture their scale and joint-like behavior.

Forward Modelling of Stimulation Response in different DFN Fabrics

The first step was to develop a base case DFN model for both the Upper and Lower Montney wells with a view to understanding the basic response of the two layers to stimulation. These initial

simulations show a number of interesting features. The Upper Montney wells stimulations comprise both induced fractures and stimulated natural structures with the pre-existing natural fracture network appearing to dominate the microseismic response.

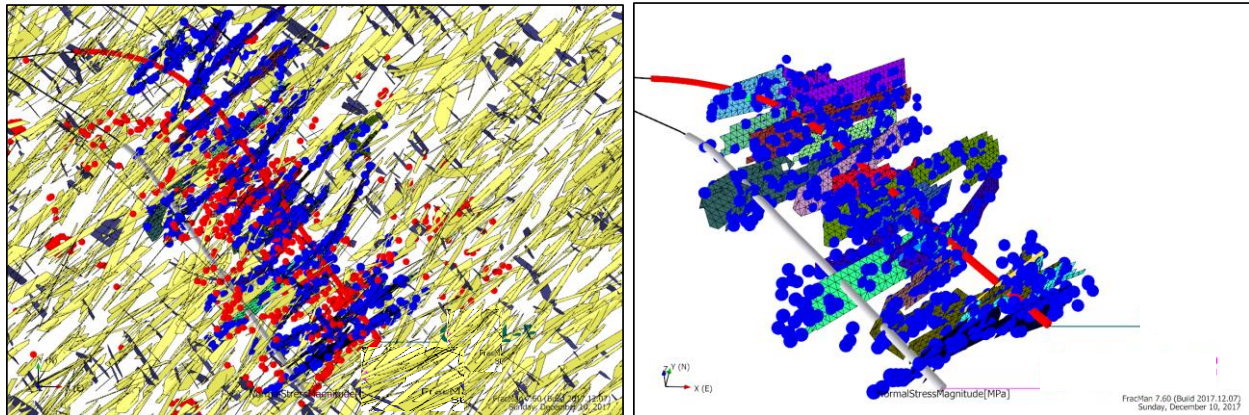


Fig. 3. FracMan hydraulic fracture simulation through an Upper Montney DFN fabric (yellow) with observed microseismic response (red) and simulated response (blue) shown. Right hand image is just the stimulated fractures and simulated microseismicity.

Additionally, for the Upper Montney well, microseismicity was seen extending well beyond the end of the modelled hydraulic fracture extent. This represents induced shearing on natural structures from pressure diffusion through the natural fracture system and represents structures anticipated to have virtually no increased permeability as they almost certainly won't have taken any proppant. Upper Montney stimulations showed strong zonal containment with only minor interaction with underlying zones.

In contrast, the Lower Montney completion included induced fractures (hard to see microseismically), some stimulation of NW-SE mega joints (100s m long layer-bounded structures) and considerable pressure diffusion away from the well resulting in seismic fault reactivation and downward migration of microseismicity into the Debolt. The mega joints ensure that there is a limit to the stimulated length as they appear to take some of the HF energy. It is not believed that fluid and proppant are migrating downwards into the Debolt given the high normal stresses on the faults; rather it is believed to be pressure diffusion causing the Debolt microseismicity.

To provide clearer evidence on the contrast between the Upper and Lower Montney and its potential impact on future completions, a range of differing DFN models of natural structures were generated and hydraulic fracture simulations run for the Upper & Lower wells. The goal was to both identify what was the most likely fracture system and also to demonstrate what wasn't. To achieve this, a range of different fabric DFN descriptions were developed for both the Upper and Lower Montney, where orientation patterns, dispersions and length scales were varied, and the hydraulic fracture simulations carried out through all of these different fabric models (see Fig 4). Criteria were developed for the evaluation of the goodness of fit to measure how well the simulations matched actual field response in terms of frac lengths, orientation variation, asymmetry etc. (see Fig 2).

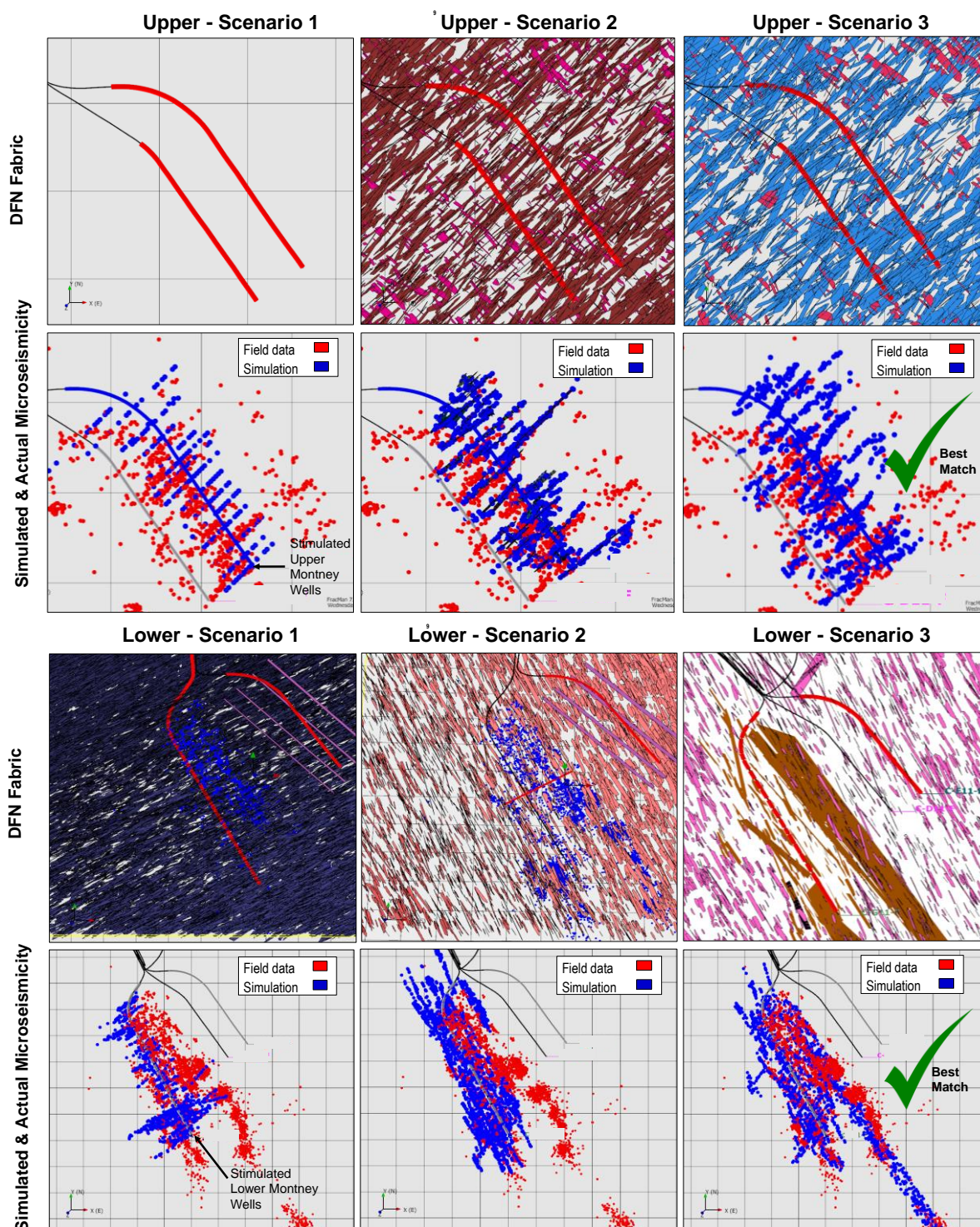


Fig. 4. Example DFN Fabric models and the resultant simulated (blue dots) and actual microseismicity (red dots) for an Upper and Lower Montney well. Green ticks indicate best match

From these simulations it was found that for the Upper Montney the best match resulted from a relatively high intensity of NE-SW structures, with a higher dispersion than originally modelled and a structural length in the order of 100s m.

The characteristics of the best match for the Lower Montney involved a relatively low intensity of NW-SE structures bounded within the Lower Montney, with connection to similarly orientated large structures that extended downwards into the underlying Debolt. Of course, this later component represents a more well-specific feature relative to proximity to faults rather than a more representative characteristic of the Lower Montney in this area.

Summary

These simulations have allowed key differences between the rock fabrics of the Upper and Lower Montney to be explored in the area in question. The Upper Montney wells simulations comprise both induced fractures and stimulated natural structures with the pre-existing fracture network appearing to dominate the microseismic response. The Lower Montney wells in contrast comprise induced fractures, some stimulation of NW-SE mega joints and considerable pressure diffusion away from the well resulting in fault reactivation and micro-seismicity in the Debolt. The mega joints may limit the stimulated length of the induced Lower Montney fracs if they take some fluid and frac energy. Despite the microseismicity observed on associated faults in the underlying Debolt, they are most likely responding to pressure diffusion i.e. limited fluid movement.

Evidence shows that the Lower Montney, with its absence of a more extensive connected fabric will yield a more linear response to increased stage number as you are directly impacting increased reservoir volume (i.e. more fracs equals more production). This is in contrast to the Upper Montney where the underlying (pre-existing) fracture network appears to strongly influence the response, meaning that decreased stage spacing doesn't necessarily increase reservoir contact (i.e. more fracs will not necessarily increase contact area). This was directly tested, with a reduction in tonnage in certain upper wells resulting in no decrease in production relative to wells with higher proppant tonnage. DFN modelling and simulation has helped with understanding the natural fracture contribution to productivity in core development areas and zones. This kind of analysis provides an opportunity to tailor stimulation recipes to match the natural fracture contribution, with an opportunity for increased recovery and/or reduced costs.

Acknowledgements

The authors would like to thank Painted Pony Energy Ltd for permission to publish this paper.

References

W. Dershowitz, M. Cottrell, D.H. Lim & T. Doe. 2010. A discrete fracture network approach for evaluation hydraulic fracture stimulation of naturally fractured reservoirs. ARMA 10-475.