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DISCRETE FRACTURE NETWORK MODELLING OF HYDRAULIC FRACTURING IN A STRUCTURALLY CONTROLLED AREA OF THE MONTNEY FORMATION, BC

Steve Rogers
Golder Associates Ltd
Pat McLellan
McLellan Energy Advisors Inc
Gordon Webb
Golder Associates Ltd

Introduction

The Farrell Creek dry gas field is located in north-eastern British Columbia, approximately 75km west of Fort St. John. This paper focuses on the results of a discrete fracture network (DFN) investigation undertaken in the vicinity of the 13-36 pad drilling location where the two horizontal wells were drilled in a NW-SE orientation, laterally offset 250m from each other, and targeting the Upper Lower (UL) and Lower Lower (LL) units of the Montney Formation, these subdivisions being largely based upon a sequence stratigraphic framework [1]. This is a structurally complex area with the majority of hydraulic fracture stimulations on this pad showing atypical responses. DFN analysis and modelling was used to help understand how these structures were impacting the stimulations [2].

Data Analysis and DFN Synthesis

Both static and dynamic data sources were available to help characterize the geometric and hydraulic properties of the fracture/fault system. The following key data were available for fracture characterization:

- 3D Seismic Cube/Ant Tracker Analysis [3] – these data yielded fault location, structural size distribution data and helped bridge the orientation gap from smaller fractures to larger structures.
- Image Log Analysis – these data were available in a vertical well leg and one side track and provided fracture and orientation data. In particular these data indicated a significant difference in the fracture intensity for the Lower Montney, with the UL having a significantly higher intensity than the LL.
- Drilling losses and Production Logging Tool (PLT) data – these data provided information of the heterogeneous permeability distribution both before and after stimulation as well as the relationship between major structures, fracture intensity and injectivity.
- Microseismic responses to stimulation – these data reveal that the stimulation of this pad must involve a connected conductive network of fractures and faults (see Fig. 1). These wells showed a range of microseismic responses including: (1) lineaments evolving at 30° oblique to SHmax; (2) regardless of what interval of the Lower Montney was stimulated, an identical spatial response was observed, (3) a virtual absence of seismicity in the Upper Lower Montney even when directly stimulated; and (4) a temporal pattern of events consistent with the diffusion of pressure around a conductive propped fracture and a connected network of natural fractures.

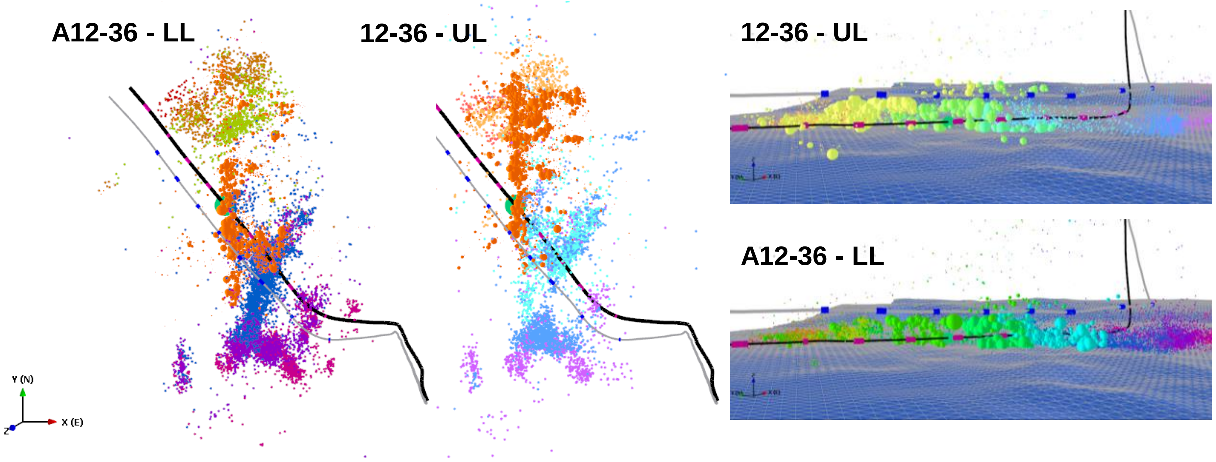


Fig. 1. Microseismic responses for wels A12-36 and 12-36 showing almost identical behaviour even though they are in different stratigraphic units. The right hand sections show that the regardless of whether the UL or LL are stimulated, the majority of the microseismicity occurs in the LL.

All of the structural and geomechanical observations [4] were compiled into a initial conceptual fracture model (Fig 2) that seeks to describes the style and distribution of fracturing within the Lower Montney and how that explains the dynamic response to stimulation,:

- The Upper Lower (UL) is comprised of higher intensity shorter fractures that are largely confined within the UL layer (Fig. 2 (A)).
- The Lower Lower (LL) is comprised of lower fracture intensity but longer structures which are thought to at least partially penetrate up into the UL layer (Fig. 2 (B)).
- Multi-zone hydraulic fracturing (Fig. 2 (C)) or the direct stimulation of major structures at or near the perforations (Fig. 2 (D)) or a combination of both occurs.

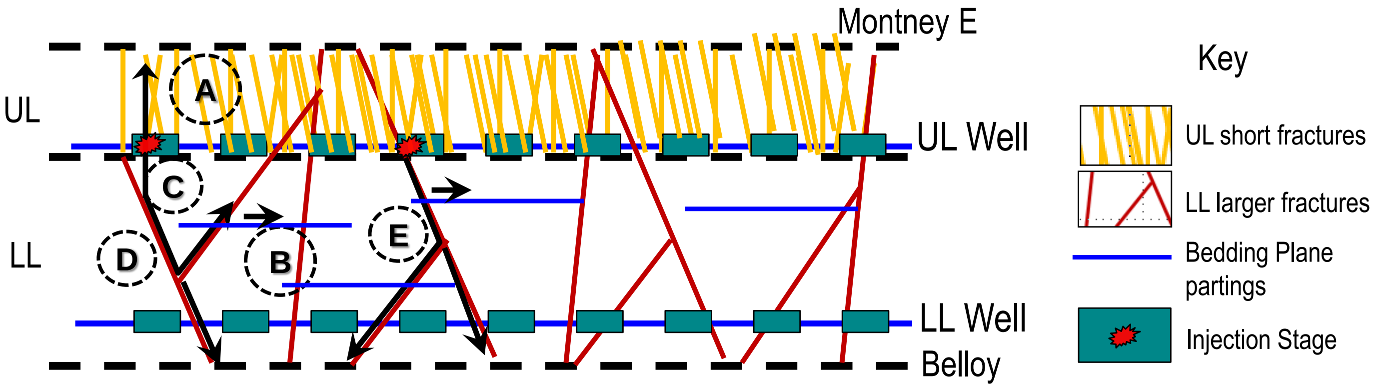


Fig.2. Conceptual model of the architecture of discontinuities in the Lower Montney, Pad 13-36. Letters relate to text above

A view of a single DFN realisation that draws upon the conceptual architecture and uses properties derived from the analysis is shown in Fig. 3. The overall connectivity of the DFN can be investigated by identifying all fractures that are connected together, as shown in Fig. 3C.

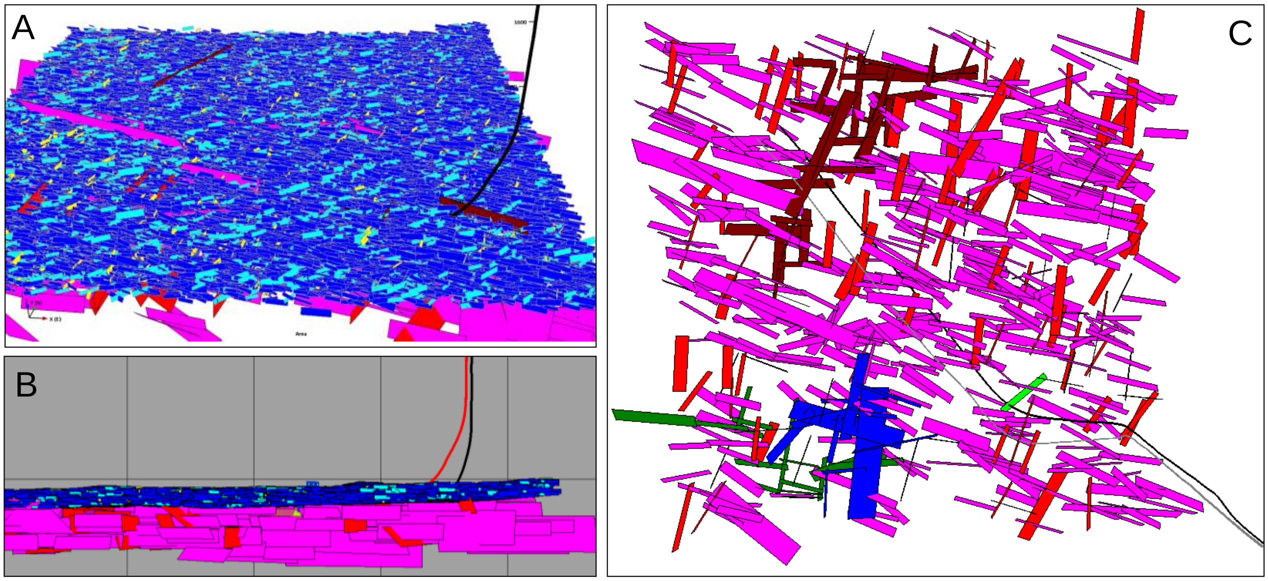


Fig. 3. Views of DFN model components in the Lower Montney. A and B show the larger and sparser Lower Lower fractures (red and purple) and the smaller more intense Upper Lower fractures (blue). C. Cluster analysis of the Lower Lower DFN identifies discrete clusters which are coloured differently.

DFN modelling of Hydraulic Fracture Development

Hydraulic fracturing was simulated in this structurally complex setting using Golder's FracMan software [5]. FracMan can rapidly simulate fluid injection using a rule based methodology, allowing complex geometries to be tested in a computationally efficient way [6]. FracMan allows hydraulic fractures to propagate inside a naturally fractured medium. Fluid will leak from the hydraulic fracture to natural fractures if the fluid pressure is greater than the closure stress in that fracture. These are called inflated normal fractures and have components of both extensional dilation and shear. A series of simulations using both the stochastically generated DFN models and deterministically generated DFN models (Fig 5 right) were tested. However the extent that fluid was moving away from the well was highly limited in relationship to the observed microseismicity and so this clearly isn't representing an effectively stimulated volume.

Critical stress analysis [7] was carried out upon natural fractures observed from image logs, as shown in Fig 4. It can be seen, even at pre-stimulation pore pressure conditions, that a considerable number of fractures are critically stressed (i.e. above the Mohr Coulomb failure criteria line), with these related to NNE-SSW and ENE-WSW striking structures. When the general form of the induced microseismic data are examined, it can be seen that the main orientation trends follow those predicted from critical stress analysis, as shown in Fig. 4.

This analysis provides some evidence that during injection, the most favourably oriented fractures and faults for shear failure (i.e., those with the highest ratio of shear stress to normal stress) are re-activated, resulting in the generation of microseismicity along their length. With elevated pore pressures diffusing along these structures resulting in a reduction in effective stress, shear re-activation is expected. However at this time, the magnitude of the shear-related dilation is unknown but is the subject of ongoing research.

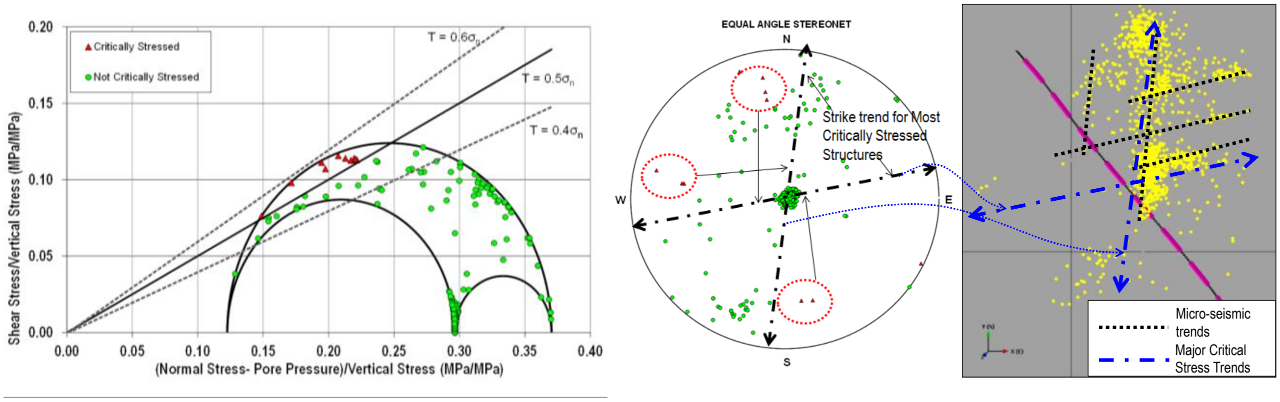
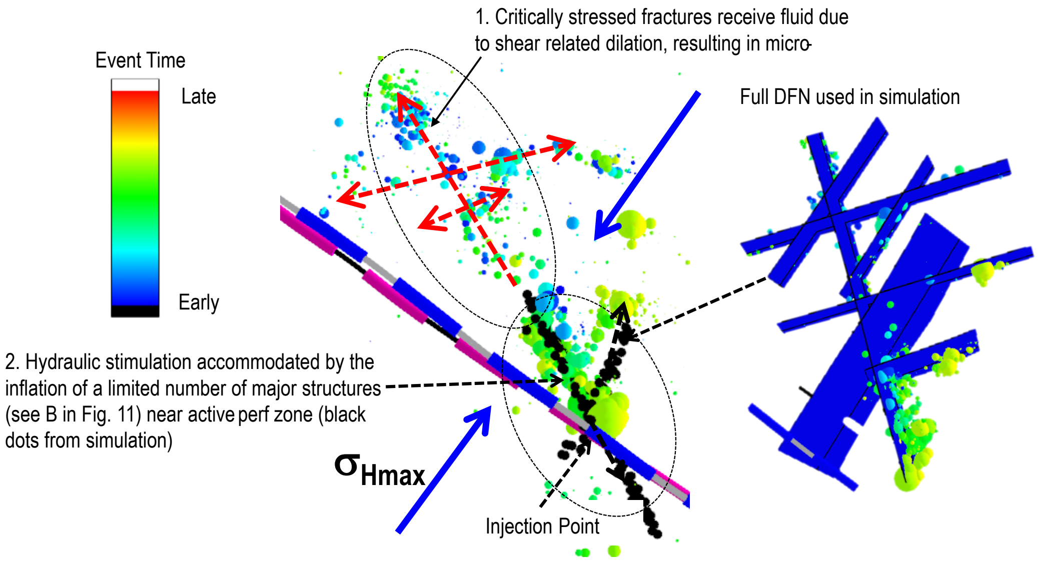


Fig.. 4. Critical stress analysis of fractures under pre-injection conditions showing some fractures reach shear failure (red triangles). Display of critically stressed fractures orientation trends showing agreement with the observed microseismic lineaments.

Integration

It is believed that a number of differing geomechanical processes are controlling the stimulation response that explains some of the anomalous observations. Natural fracture dilation under primarily extensional conditions occurs relatively close to the wellbore. For example see the black dots on Fig. 5 from FracMan simulation showing strong agreement with strongest microseismic response. Additionally, as fluid is being injected into a connected fracture system, this increases the pore pressure, causing a reduction in the effective normal stress on structures, resulting in the shearing of these structures and the generation of additional microseismicity at distance. Note how the microseismic response on the features in Fig. 5 outside the near-wellbore propped zone, show a much lower signal-noise ratio (SNR). The timing of these more distant events shows that these are the early events (as shown by their colour), consistent with rapid pressure transmission through natural structures. However in the presence of conductive fractures prone to shear dilation and given the relatively high permeability of these structures (relative to the intact matrix), it is much more likely that these structures will take fluid in preference to breaking new rock.



1. Critically stressed fractures receive fluid due to shear related dilation, resulting in micro-

2. Hydraulic stimulation accommodated by the inflation of a limited number of major structures (see B in Fig. 11) near active perf zone (black dots from simulation)

Fig.. 5. Example microseismic response from a frac stage showing early shear events at distance along existing structures and closer to the well, later propping of natural fractures as reproduced by DFN simulation (black dots).

Acknowledgements

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