Fracture Characterization: From Core to Discrete Fracture Network Model*

Doug Bearinger[1] and Chelsey Hillier[2]

Search and Discovery Article #41908 (2016)**
Posted October 3, 2016

*Adapted from oral presentation given at AAPG 2016 Annual Convention and Exhibition, Calgary, Alberta, Canada, June 19-22, 2016

[1]Nexen Energy ULC, Calgary, Alberta, Canada (doug_bearinger@nexeninc.com)
[2]Nexen Energy ULC, Calgary, Alberta, Canada

Abstract

Geomodeling of naturally fractured reservoirs involves scale-up challenges that are not faced in conventional reservoirs. Matrix properties can be reasonably well measured at the core scale and applied to the reservoir scale, whereas the distributions of the fracture properties observed in cored and imaged wells must be scaled to account for the larger features that dominate flow in fractured reservoirs. Fractures described in core and those interpreted in image logs allow the identification of fracture sets and their properties. Often the most important flow features are too sparsely distributed to be sampled in a single well. Even if one of these larger features is intersected by a well, the size of the fracture cannot be determined. For reservoirs with mainly vertical fractures, deviated and horizontal wells can provide good estimates of fracture intensities after accounting for sampling bias. In wells oriented to cross fractures, the aperture is only fracture dimension that can be measured directly from core or estimated from wellbore images. Vertical wells have the possibility of drilling parallel to many fractures allowing fracture heights to be measured as well. To build a Discrete Fracture Network model (DFN) both the fracture sizes and intensities must be scaled to obtain the truncated size distribution relevant to flow modelling. The extreme sample bias of a vertical well requires a robust correction to determine fracture intensities. It is helpful to have fracture measurements from inclined or horizontal wells to ensure that the fracture intensities obtained from vertical cores are reasonable. Core provides the highest resolution from the smallest sample allowing description of smaller fractures not resolved by the image log. Fracture observations suffer from two factors that limit the useful size distribution, truncation (minimum size detected or measured) and censoring (inability to adequately sample large features). Care must be taken to use the appropriate distribution function by fitting curves within the region that is not impacted by truncation or censoring. This presentation describes the process used to scale vertical core observations to the inputs needed for a realistic DFN model of a shale reservoir. The impact of the fracture size-intensity scaling is demonstrated with model results that are able to match other observations.

Reference Cited

Baecher, G.B., and N.A. Lanney, 1978, Trace Length Biases in Joint Surveys: 19th U.S. Symposium on Rock Mechanics, University of Nevada, Reno, p. 56-65.

Berg, C.R., 2012, The Effect of Fracture and Borehole Orientation on Fracture Frequency and Density: Copyright © 2012 by Charles R. Berg, 43 p. http://www.resdip.com/docs/fracture%20orientation.pdf Website accessed September 2016.

Bonnet, E, O. Bour, N.E. Odling, P. Davy, I.G. Main, and B. Berkowitz, 2001, Scaling of Fracture Systems in Geological Media: Reviews of Geophysics, v. 39/3, p. 347-383. doi:10.1029/1999RG000074

Cladouhos, T.T., and R. Marrett, 1996, Are Fault Growth and Linkage Models Consistent with Power-Law Distribution of Fault Length?: Journal of Structural Geology, v. 18, p. 281-293.

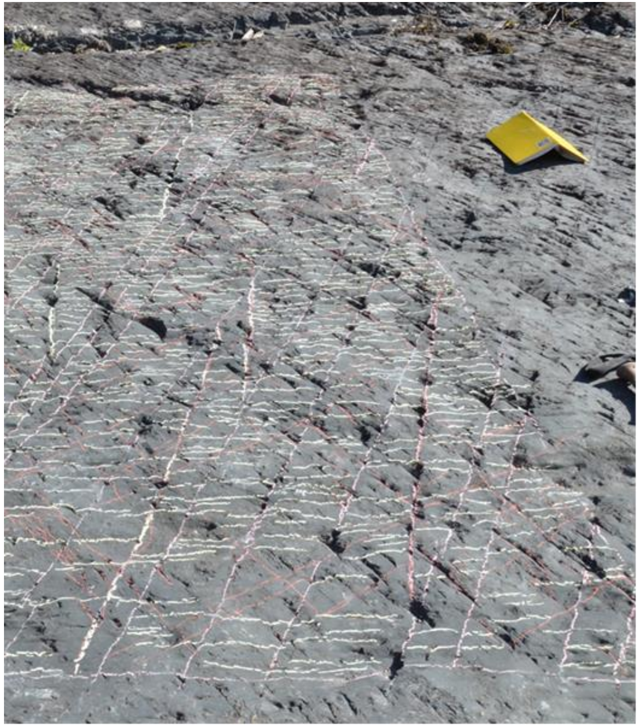
Fracture Characterization

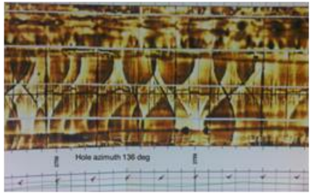
FROM CORE TO DISCRETE FRACTURE NETWORK MODEL

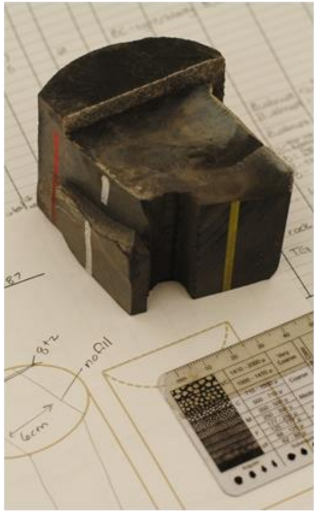
Doug Bearinger, Chelsey Hillier

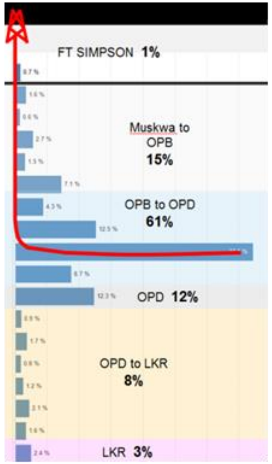
AURORA LNG IS A JOINT VENTURE BETWEEN NEXEN ENERGY ULC (A CNOOC LIMITED COMPANY) & INPEX GAS BRITISH COLUMBIA LTD. (IGBC)

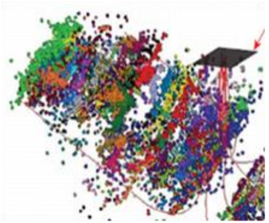
From core To Discrete Fracture Network Model

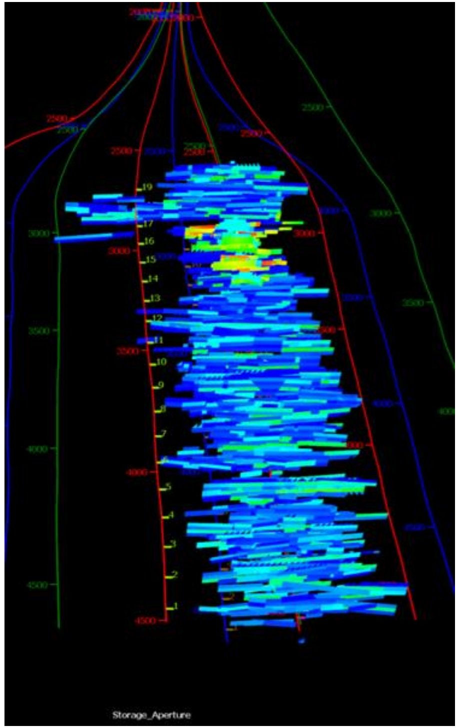










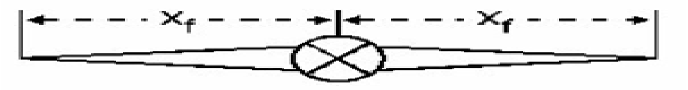


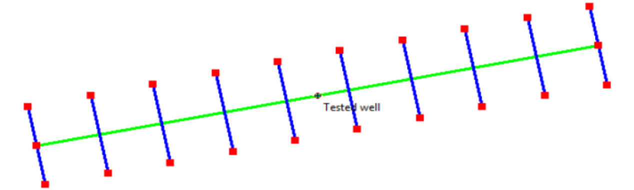
AURORA LNG IS A JOINT VENTURE BETWEEN NEXEN ENERGY ULC (A CNOOC LIMITED COMPANY) & INPEX GAS BRITISH COLUMBIA LTD. (IGBC)

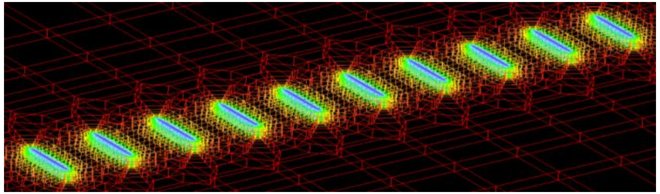
Shale challenges

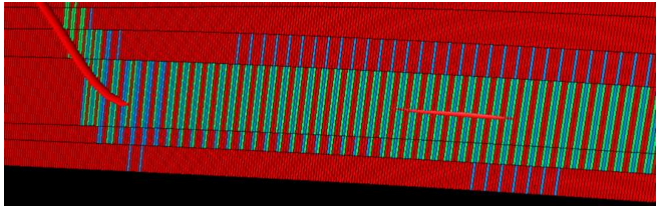
Simple models versus observations of **complex fracture networks**

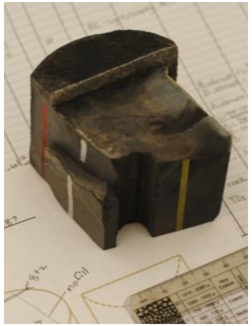
A good earth model should use fracture characteristics as inputs and yield results that match observations

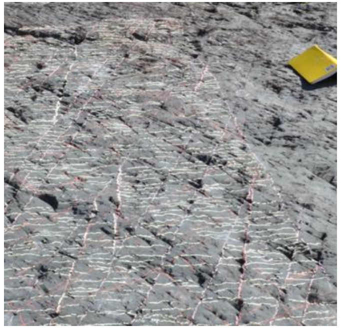




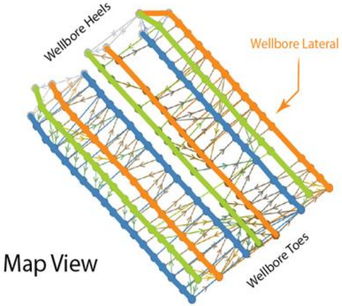




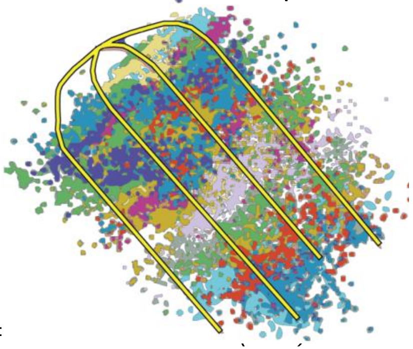




Frac Pressure hits

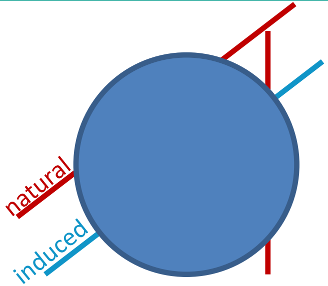


Microseismic Response



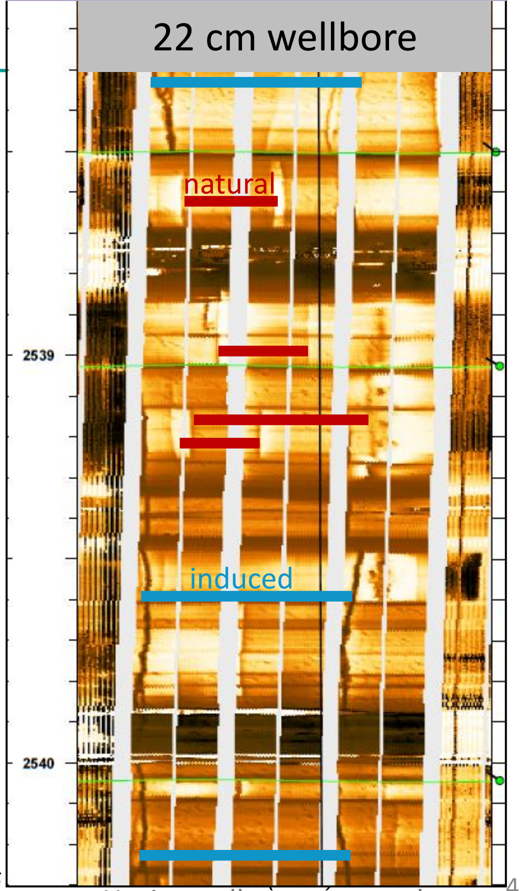
Vertical well sampling

- Very few natural fractures imaged in vertical wells
  - Much of the image has no discernable natural fractures
  - Bed bound fractures occur as vertical pairs
    - Resistivity halo suggests mineralization on fracture walls
- Core samples show many more fractures
  - Shows cement fill, type
  - Many fracture heights are observed



9 cm core

Short section where a few natural fractures are imaged (more than typical)



Horizontally exaggerated

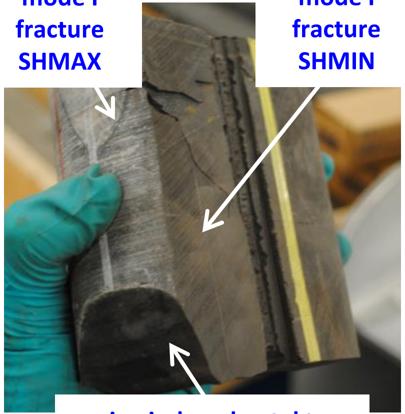
Natural fractures from core

Sets

Fracture orientation

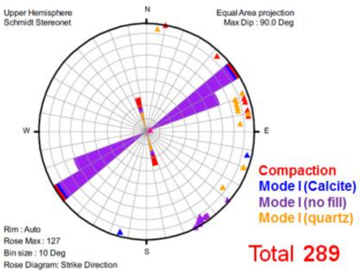
mode I fracture SHMAX

mode I fracture SHMIN



coring induced petal to petal-centerline

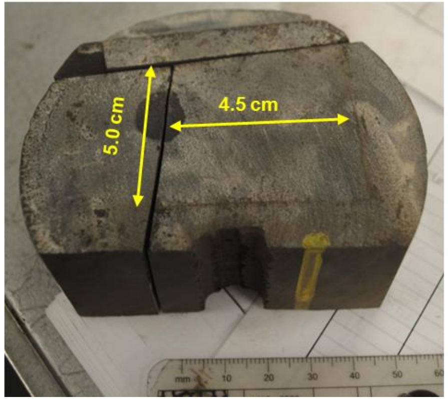
CORE LOGGING



Properties

Fracture spacing/intensity

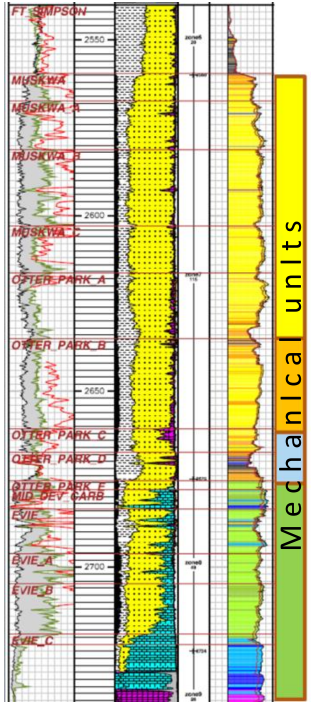
mode I – NE-SW & NNW-SSE



Fracture Heights

Zonation

Mechanical Stratigraphy



aurora LNG

nexen A CNOOC LIMITED COMPANY

INPEX

Fracture sampling bias

- Fracture observations from wells have sampling biases
- Correction methods were tested using a 3D DFN model
- The methods tested:
  - Terzaghi (intersection angle applied to spacing)
  - Vector projection (intersection angle applied to scan line)
  - Narr (intersection angle and borehole diameter)
  - **Berg (intersection angle, borehole diameter, fracture height)**
  - **P21 projection (sum of fracture lengths/perpendicular cross-sectional area of borehole or core)**

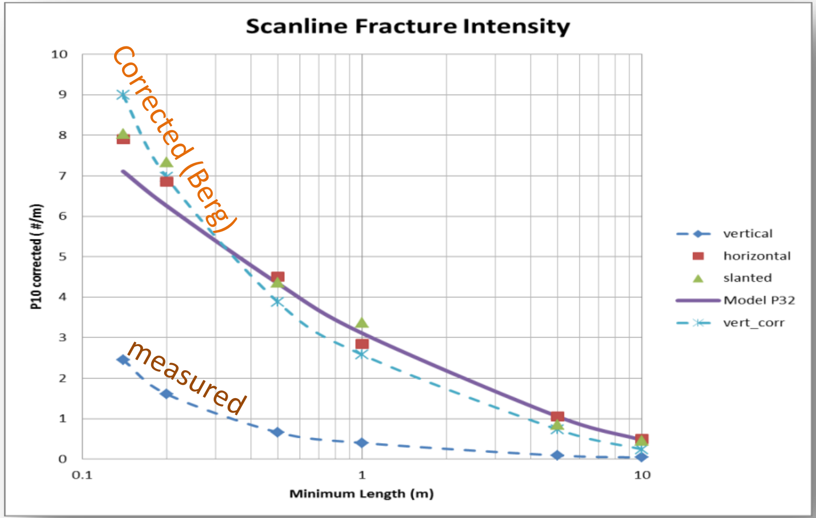
$$F = \frac{\sin \beta}{S}$$

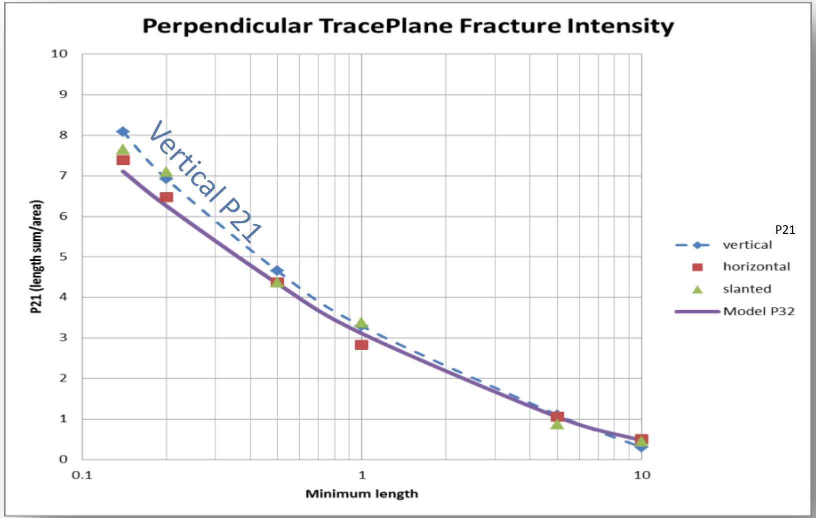
$$F = \frac{\sin \beta}{S} + \frac{D}{S \cdot H}$$

THE EFFECT OF FRACTURE AND BOREHOLE ORIENTATION ON FRACTURE FREQUENCY AND DENSITY
Copyright © 2012 by Charles R. Berg
http://www.resdip.com/docs/fracture%20orientation.pdf

DFN simulation of intensity measures

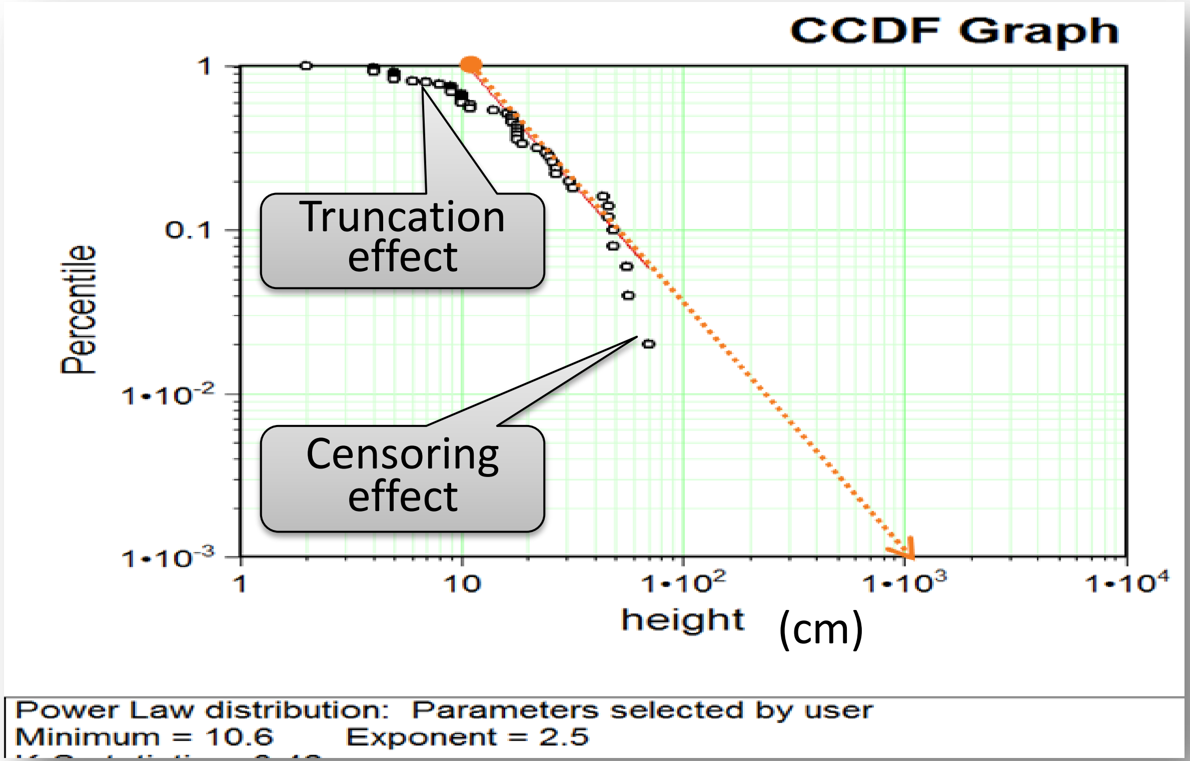
- Simulated fracture volume explored by vertical, horizontal and 26° inclined wells
  - Mean fracture dip is 3° from vertical
  - Scanline method with correction for angle and core width- (vert_corr) (Berg)
  - P21 Perpendicular area (traceplane) method





Fracture size distribution

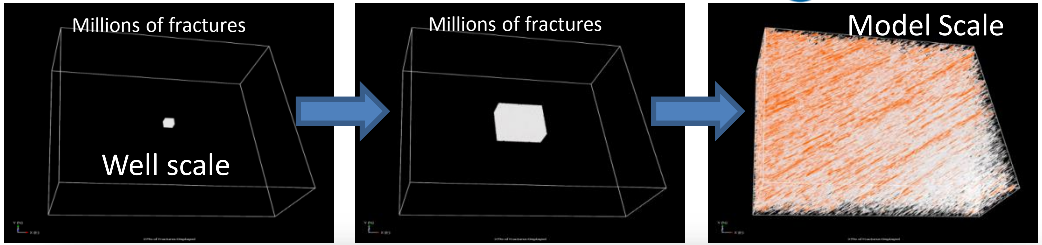
- Power Law fits many field fracture length observations and the extension-linkage process of fracture growth *(Cladouhos & Marrett 1996)*
- Fit must avoid the tails of the data distribution where observations are incomplete
- *Baecher and Lanney, 1978*
- *Bonnet et al Aug 2001, Scaling of Fracture Systems in Geological Media, Reviews of Geophysics*

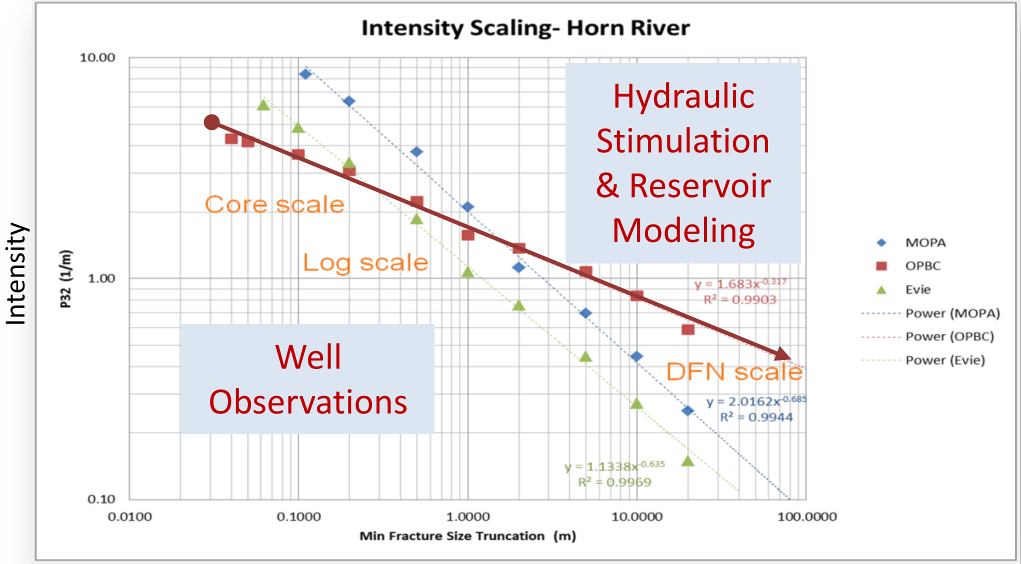


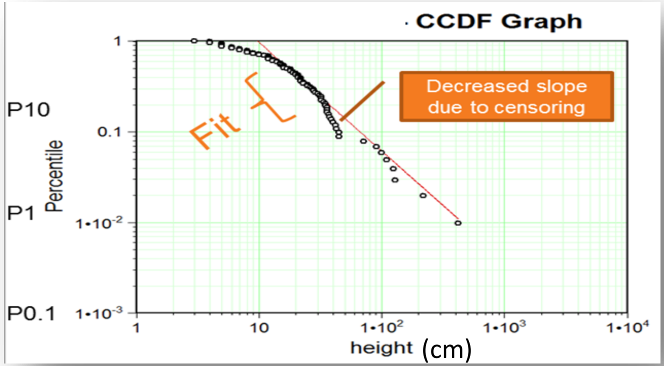
Fracture size and intensity scaling

DFN model scale up

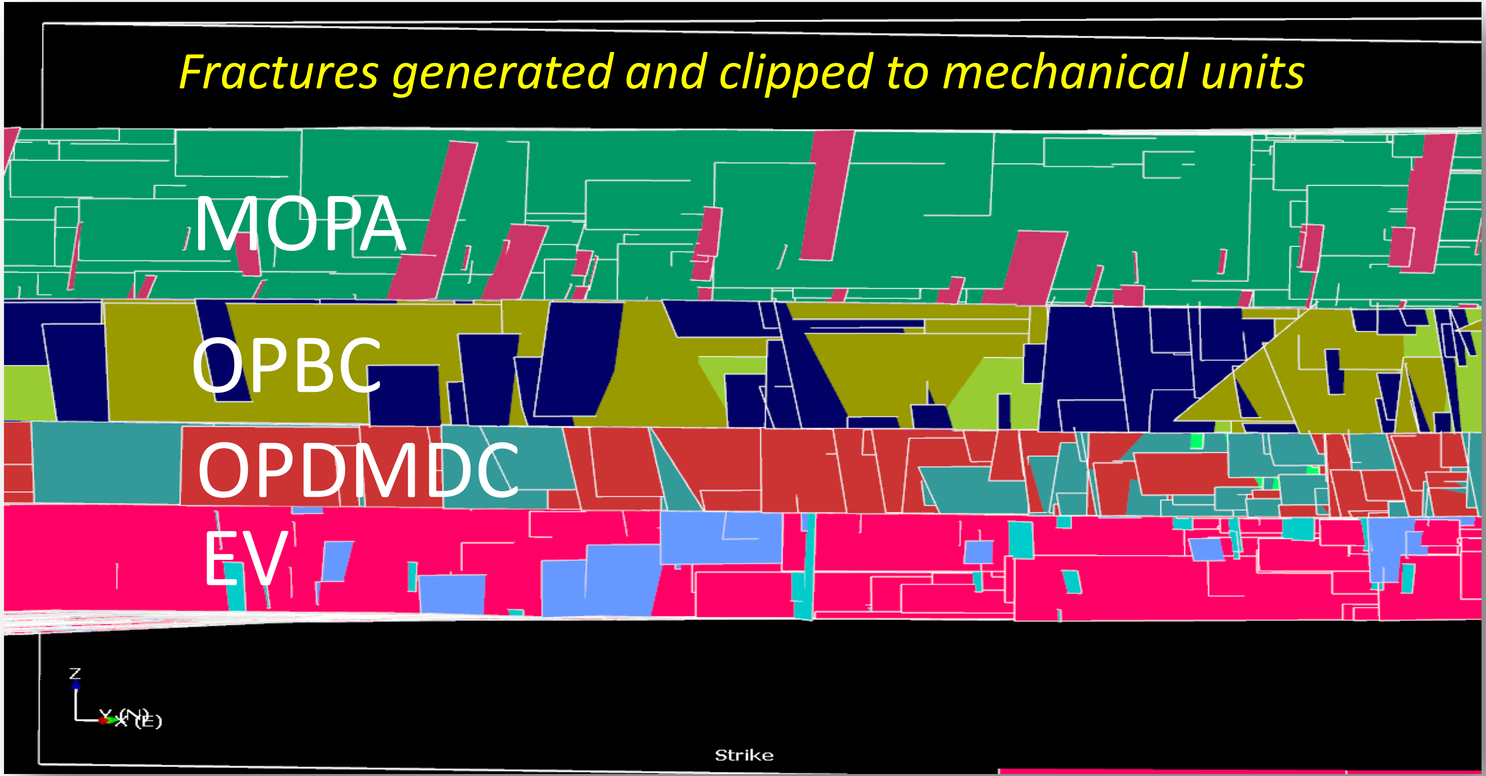
- Relative fracture intensities change with size
  - Observations are made at several scales
  - Most intensively fractured zones in core are the least fractured at the reservoir scale where all the small fractures are truncated from the distribution





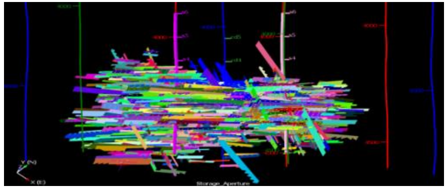


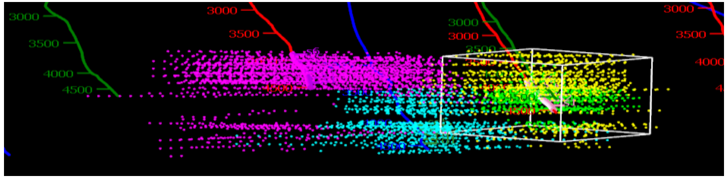
Side view of model

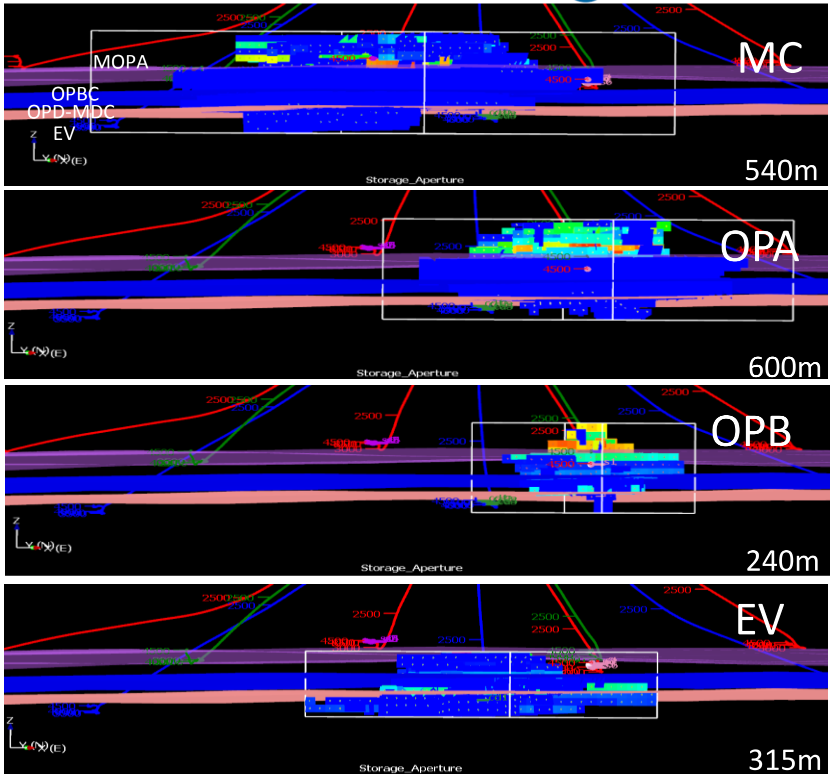


DFN results (HydroFrac simulation)

- SRV's show dimensions similar to those determined from Microseismic
  - MC>OPA~EV>OPB
- Vertical distributions are also similar to microseismic
  - Show that CFT's would mix between fracs from different completions zones



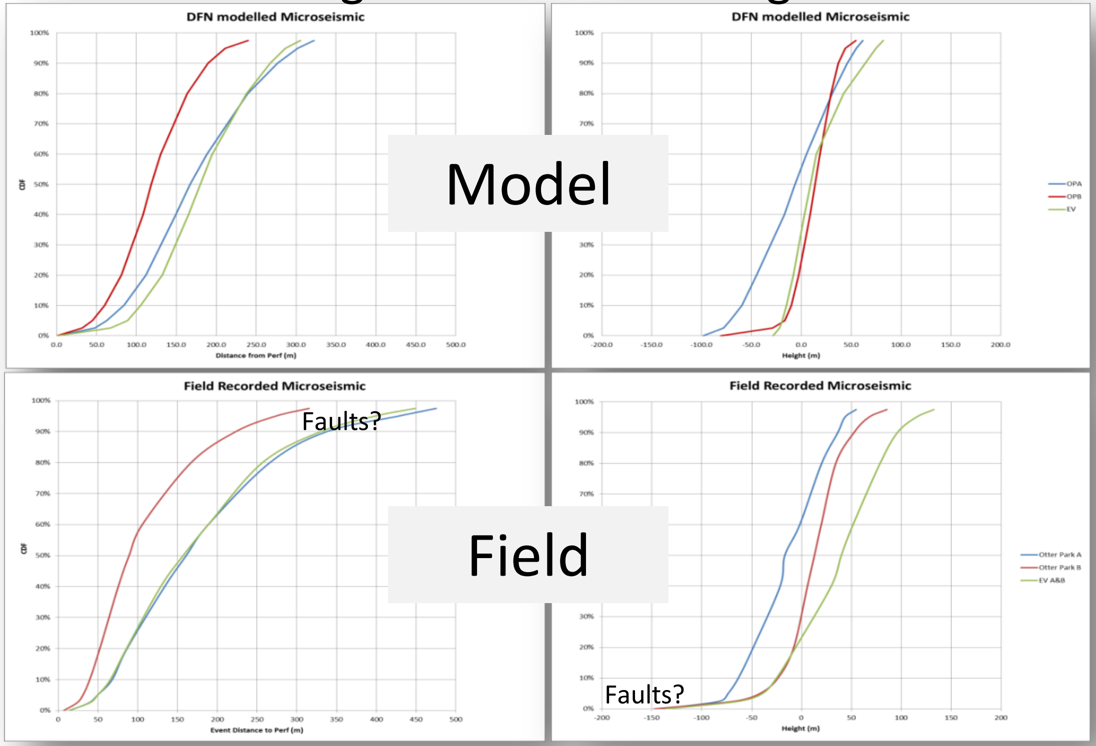




Microseismic event distribution

- Modelled microseismic distribution is similar to field observations
- Major difference is for the OPB zone where fracture size-intensity scaling had the highest fracture intensity
  – More compact SRV for OPB fracs
- DFN model does not contain faults
  – Adds more distant events and deeper events

Lateral growth Vertical growth



Acknowledgements

- Many thanks to Nexen, INPEX and JGC for supporting this work
  - The Horn River Shale Gas team for acquisition and analysis of
    - Outcrop data
    - Core tests and log petrophysics
    - Seismic
    - Stresses and pressures
    - Geomechanical properties
    - Microseismic
    - Frac pressure hits
    - Chemical tracer recovery

Questions?