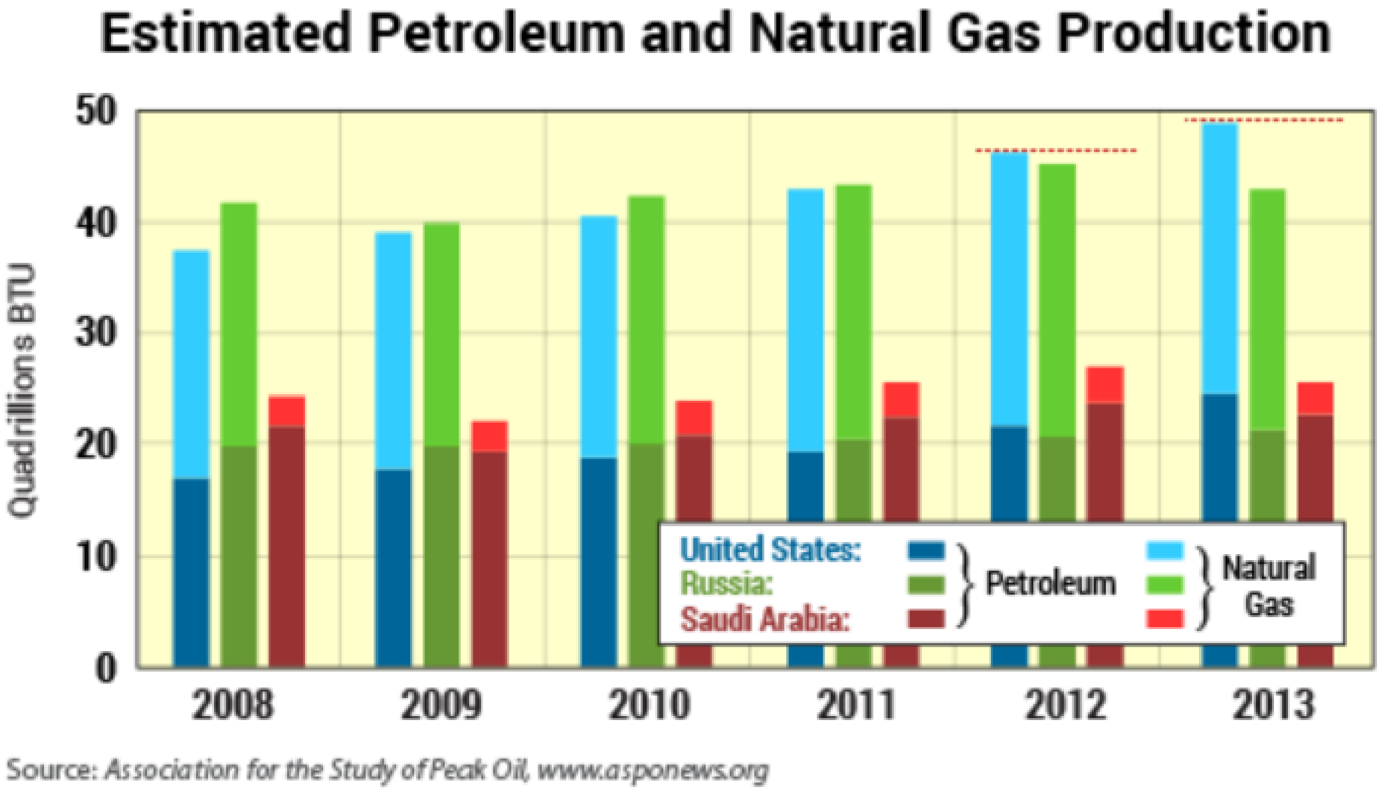
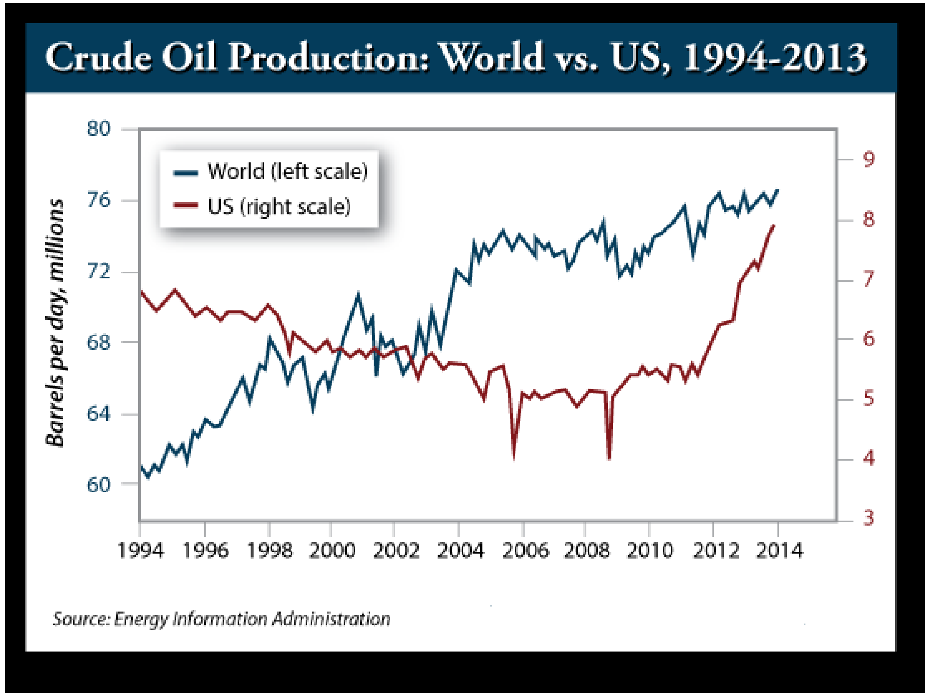
MEQ Data to validate fracture modeling results

Ahmed Ouenes
aouenes@fracgeo.com

The Boom: US is biggest energy producer since 2012!





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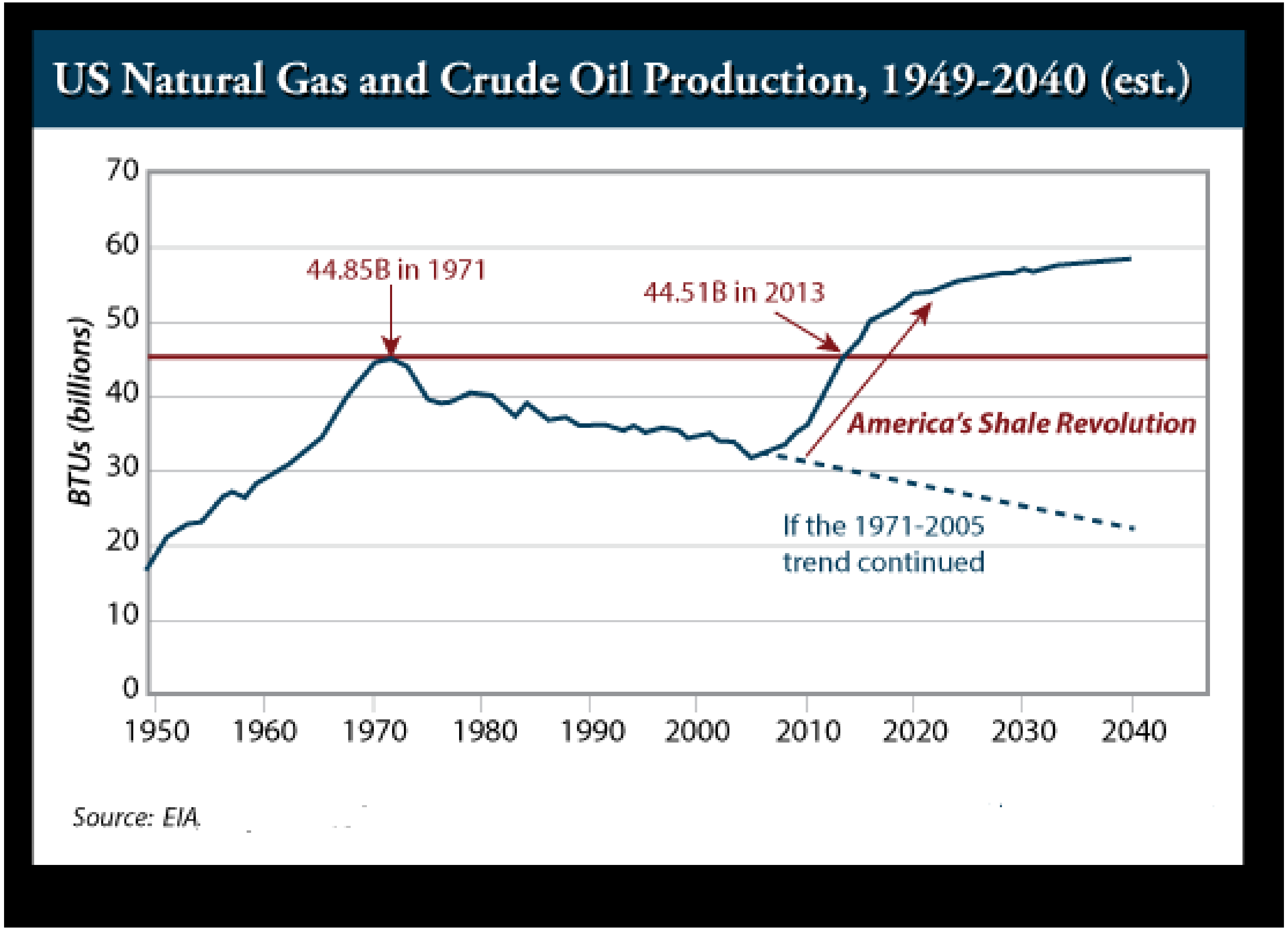
The Boom: America's shale revolution is here to stay!



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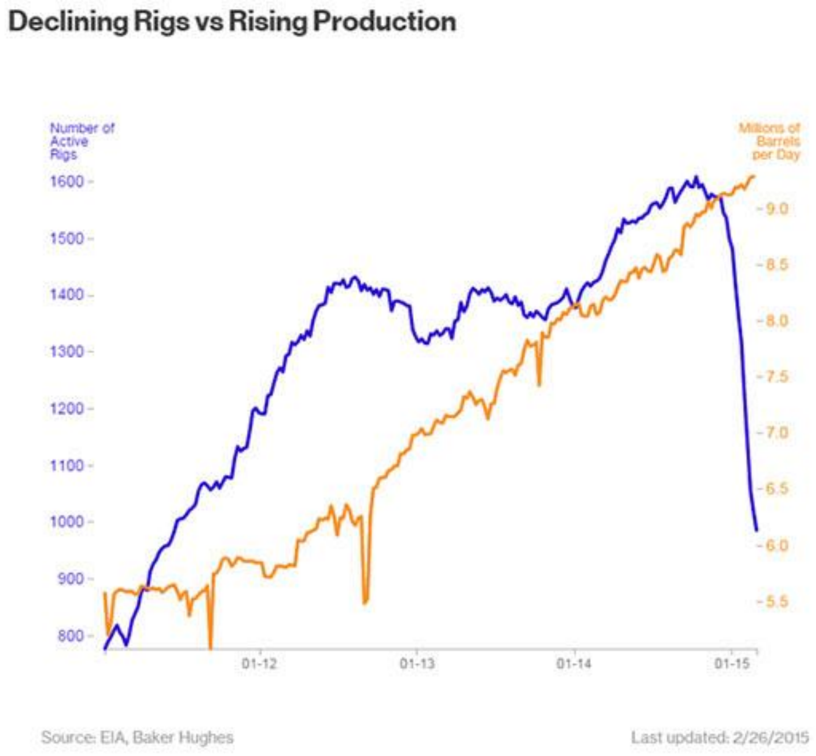
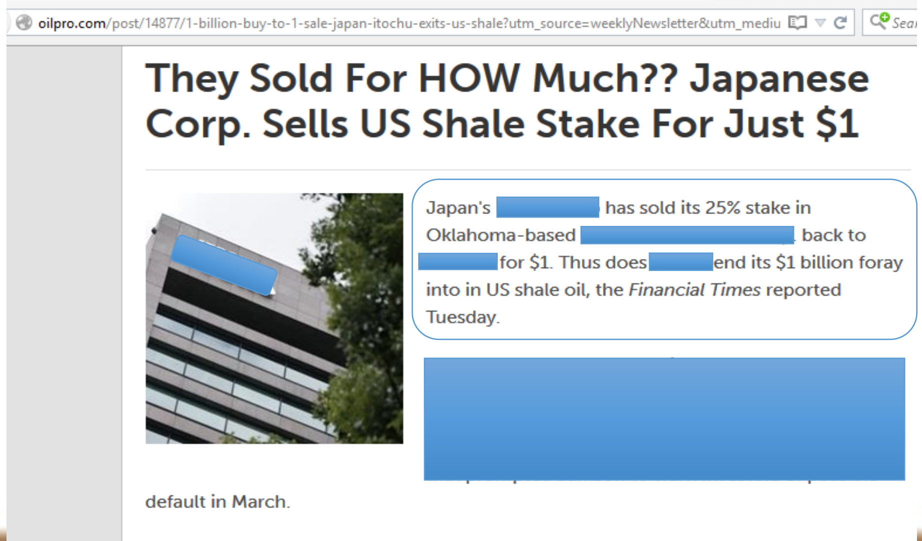
The Bust

The Economist





oilpro.com/post/14877/1-billion-buy-to-1-sale-japan-itochu-exits-us-shale?utm_source=weeklyNewsletter&utm_mediu

They Sold For HOW Much?? Japanese Corp. Sells US Shale Stake For Just $1

Japan's [redacted] has sold its 25% stake in Oklahoma-based [redacted] back to [redacted] for $1. Thus does [redacted] end its $1 billion foray into in US shale oil, the *Financial Times* reported Tuesday.

[redacted]

default in March.

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Back to the drawing board

- "An estimated 40% of unconventional wells are uneconomical due to spatial variability in reservoir characteristics, lateral heterogeneity along the wellbores, accuracy of wall placement, and variability in drilling, completion, and stimulation practices"

  SPE 172973

- Identify the key factors affecting these poor frac stages

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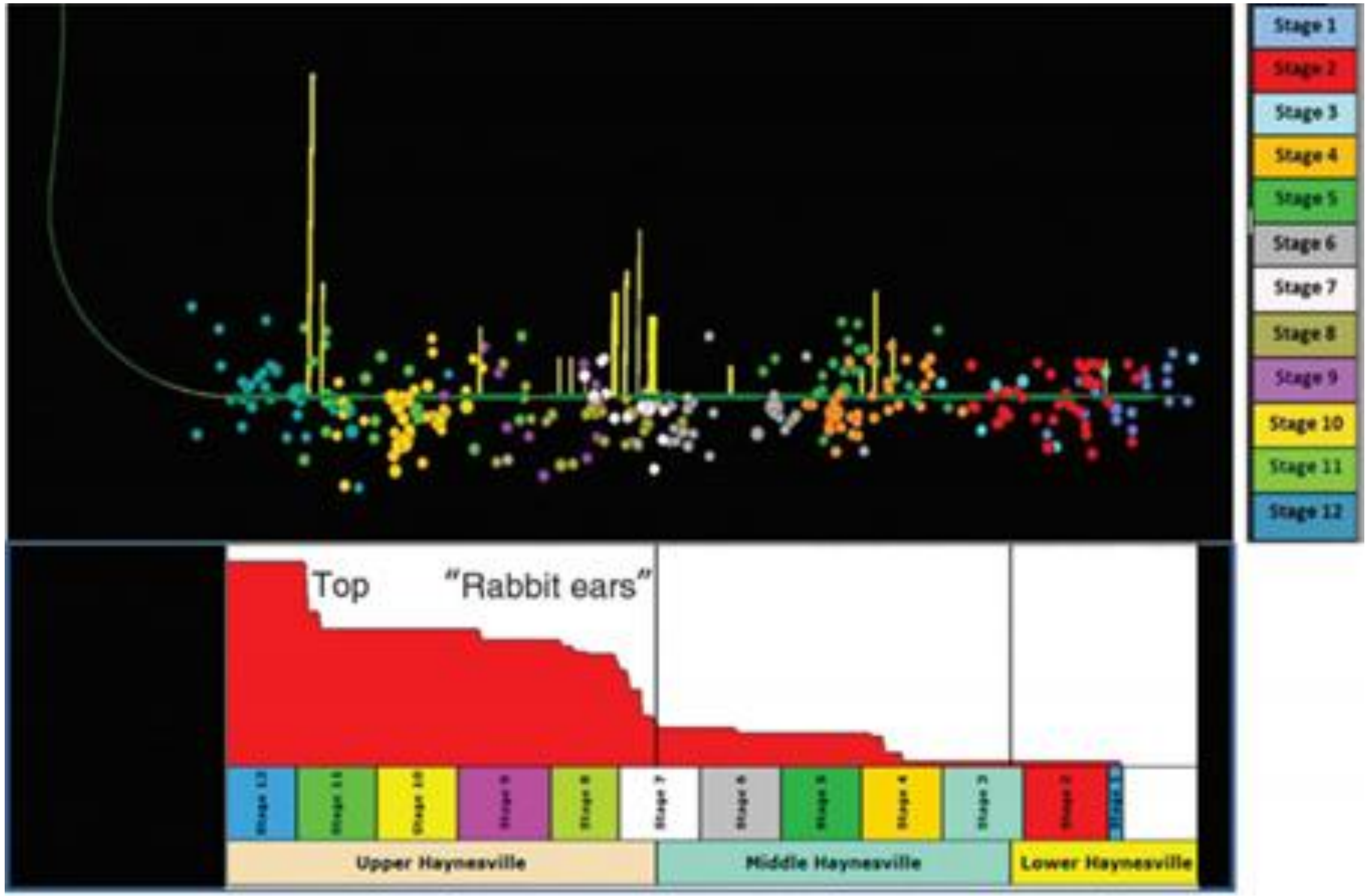
Understanding the inefficiencies



Interpretation, Nov. 2014

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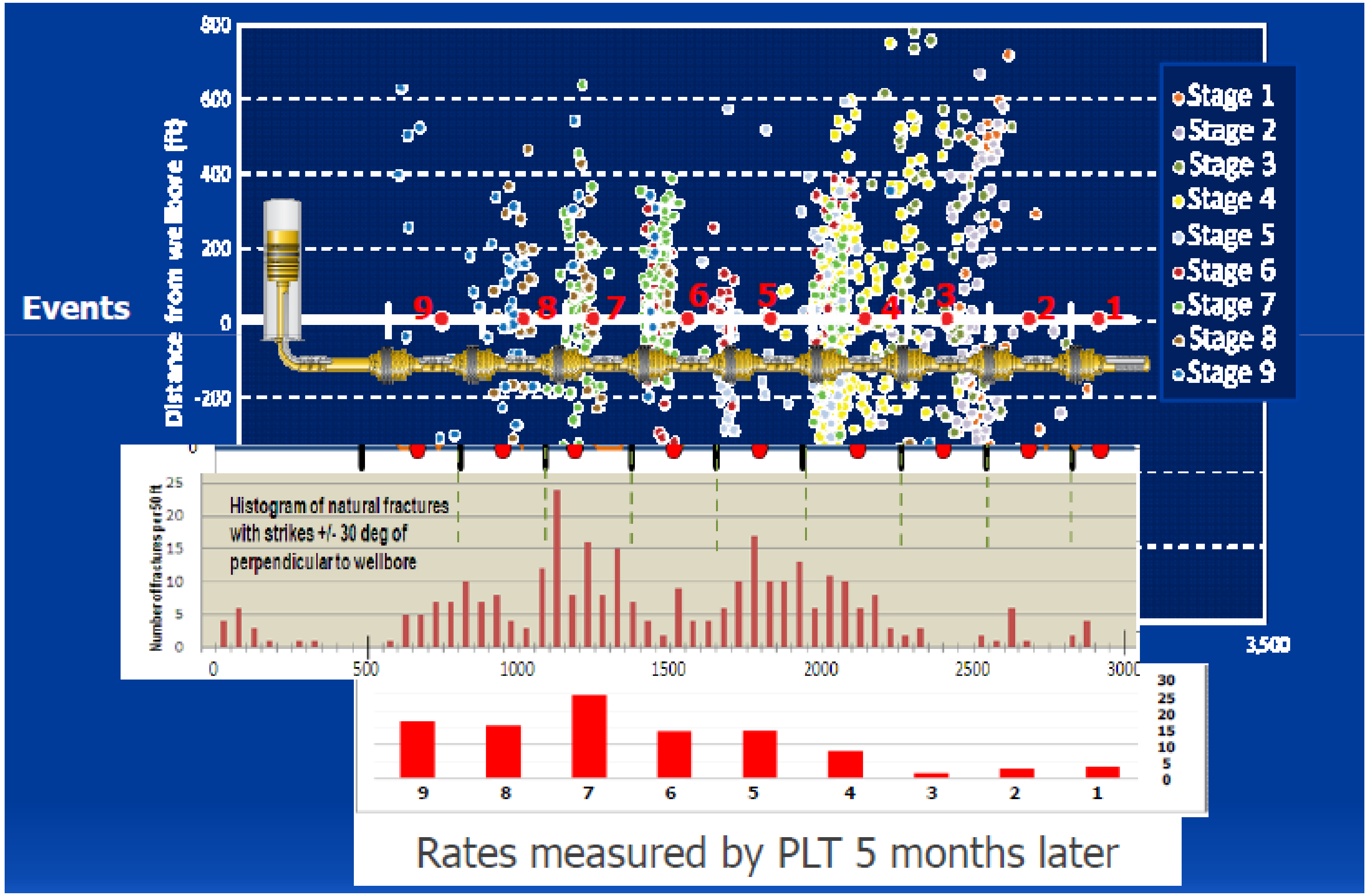
Understanding the inefficiencies



Rates measured by PLT 5 months later

Search & Discovery #41135

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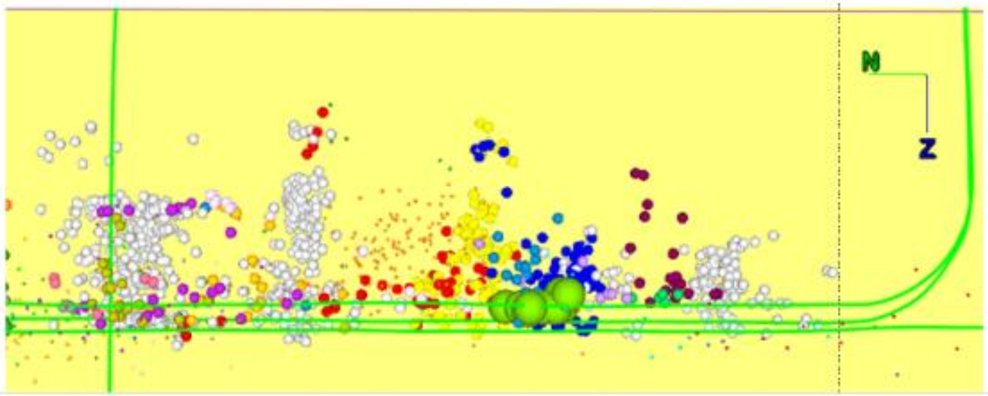
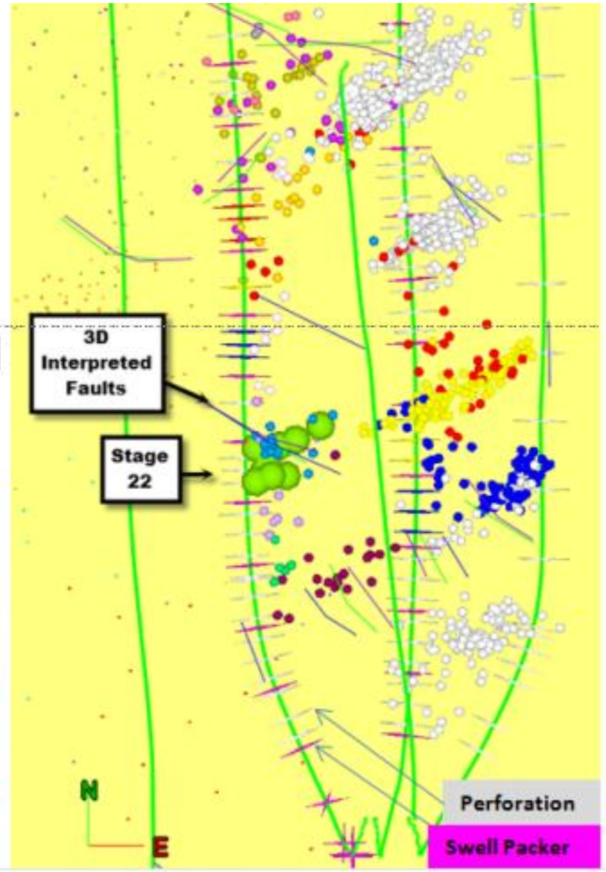
Understanding the inefficiencies

Production Log Interpretation						
Stage	Water per Stage (%)	Oil per Stage (%)	Gas per Stage (%)	Water bbl/d)	Oil (bbl/d)	Gas (1000 ft3/d)
26	0%	2%	2%	0	14	10
25	8%	2%	2%	49	11	8
24	0%	1%	1%	0	7	5
23	0%	4%	4%	0	25	17
22	21%	3%	4%	122	22	16
1 to 21	71%	87%	87%	414	544	377





SPE 169534

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Faults & Fractures

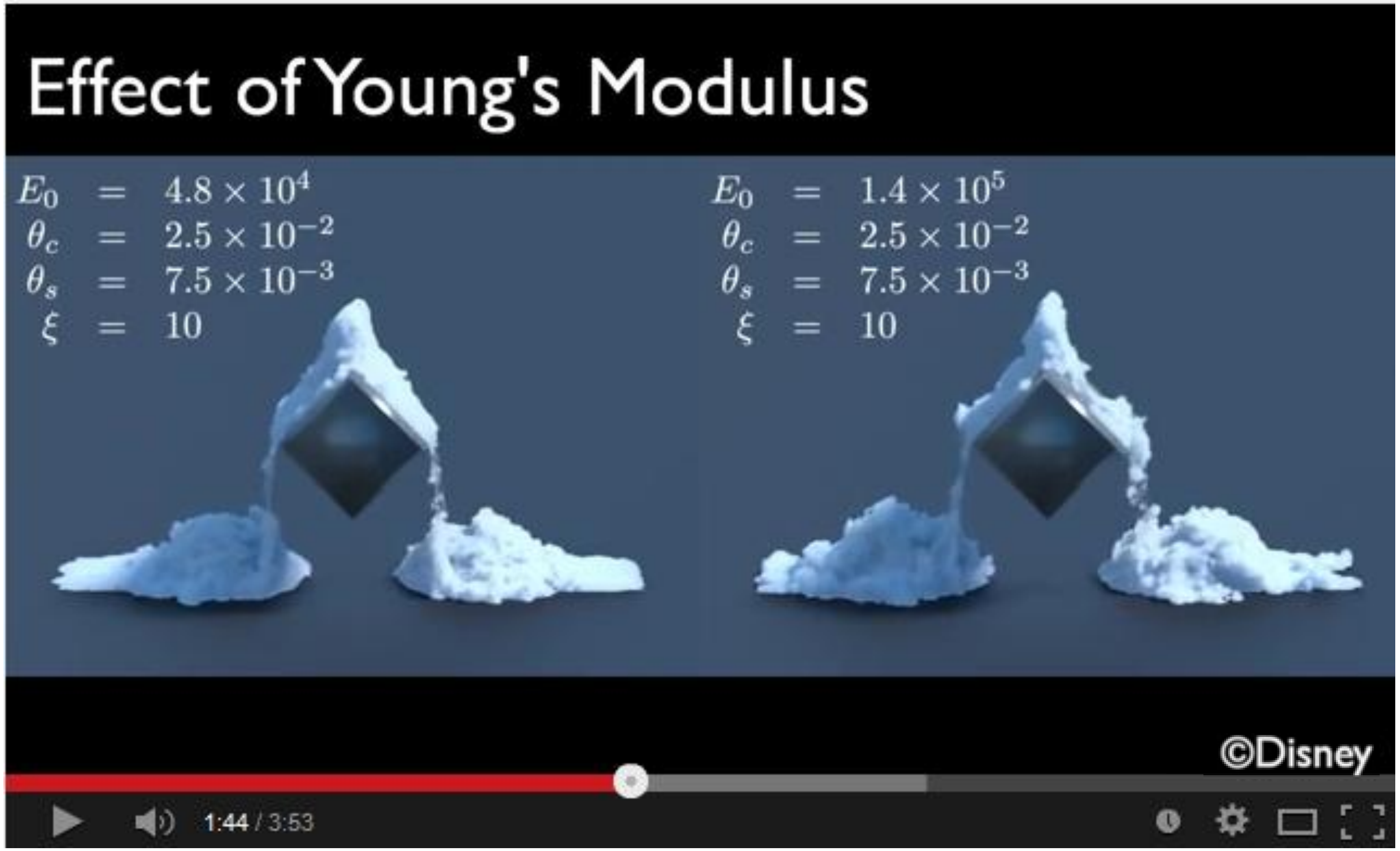
- These underestimated geologic features seem to affect in many ways the performance of shale wells throughout their life cycle

- Quantifying their effects on shale performance turns out to be a major engineering challenge

Wooden stick – Picture provided by C. Newgord

Sept 18, 2014 Curiosity Rover, Planet Mars

Who is studying the effect of Young Modulus ?



DISNEY !!!

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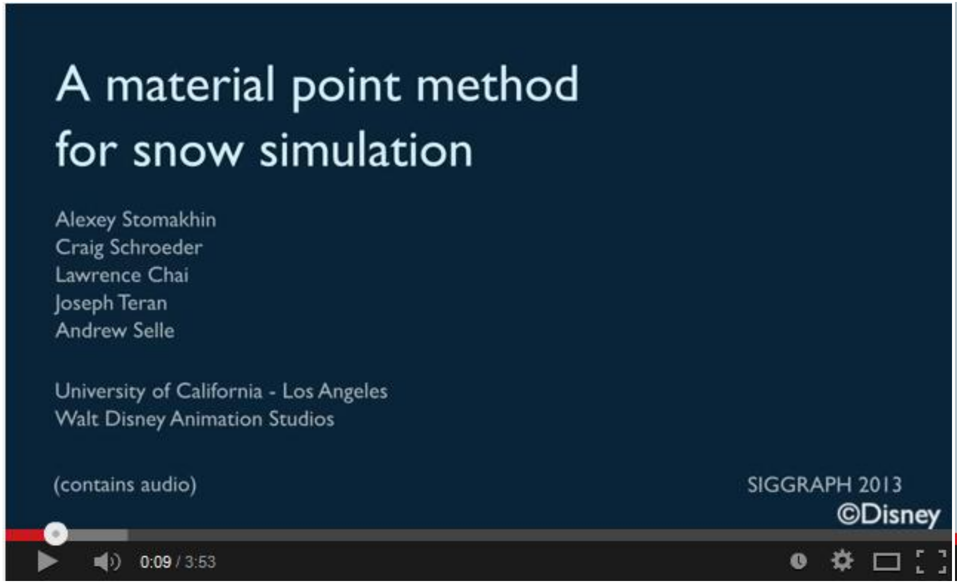
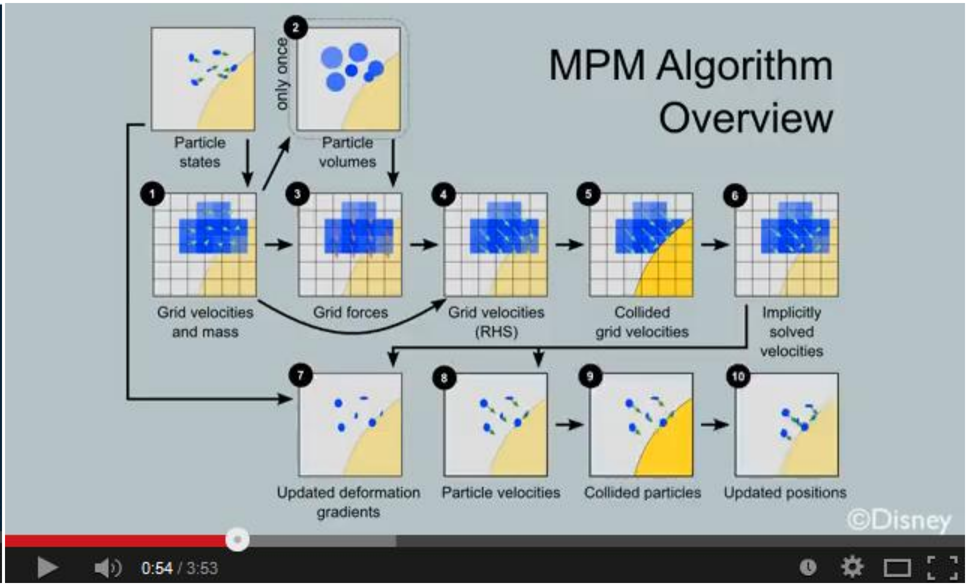
What is the highest grossing Disney Animated Movie ?

Highest-grossing animated films[1]

Rank	Title	Worldwide gross	Year	Ref
1		$1,276,472,665	2013	[# 1]
2	*Toy Story 3*	$1,063,171,911	2010	[# 2]
3	*The Lion King*	$987,483,777	1994	[# 3]
4	*Despicable Me 2*	$970,761,885	2013	[# 4]
5	*Finding Nemo*	$936,743,261	2003	[# 5]
6	*Shrek 2*	$919,838,758	2004	[# 6]
7	*Ice Age: Dawn of the Dinosaurs*	$886,686,817	2009	[# 7]
8	*Ice Age: Continental Drift*	$877,244,782	2012	[# 8]
9	*Shrek the Third*	$798,958,162	2007	[# 9]
10	*Shrek Forever After*	$752,600,867	2010	[# 10]

Material Point Method and Disney's "Frozen"





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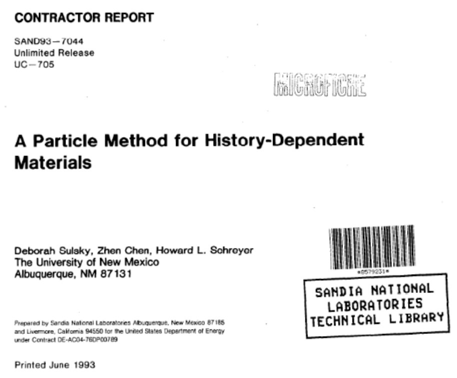
Geomechanical Modeling

- The use of geomechanics is necessary to quantify the interaction between hydraulic and natural fractures
- A new geomechanical technology (Aimene & Nairn 2014, Aimene & Ouenes, 2015), that is able to simulate the interaction of hydraulic fractures with natural fractures opens new doors to derive a better understanding of frac stage performance
- The new geomechanical technology relies on the use of the Material Point Method (MPM) and a continuous description of the fractures

Material Point Method (MPM)

- Powerful tool developed for solid dynamics problems (Sulsky, Chen & Schreyer, 1994)
- Meshless method: discretization into points, called particles
- Particles handle all material information
- Background grid associated with the particles, composed of elements.
- At each time step, particles' information are extrapolated to the background grid to solve the equations of motion


CONTRACTOR REPORT

SAND93–7044
Unlimited Release
UC–705

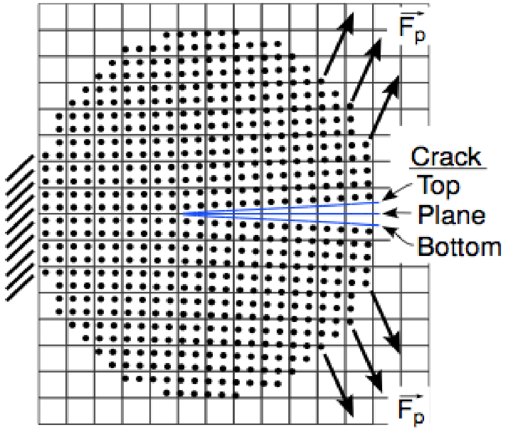
MICROFICHE

A Particle Method for History-Dependent Materials

Deborah Sulsky, Zhen Chen, Howard L. Schreyer
The University of New Mexico
Albuquerque, NM 87131

Prepared by Sandia National Laboratories Albuquerque, New Mexico 87185 and Livermore, California 94550 for the United States Department of Energy under Contract DE-AC04-76DP00789

Printed June 1993



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Equations behind MPM

- The starting point for MPM (and all dynamic numerical equations) is the momentum equation and virtual work:

Body Force Surface Traction Particle Force

$$\int_V \rho \boldsymbol{b} \cdot \delta \boldsymbol{u}\, dV + \int_{S_T} \boldsymbol{T} \cdot \delta \boldsymbol{u}\, dS + \sum_p \boldsymbol{F_p} \cdot \delta \boldsymbol{u}$$

Cauchy Stress

Density Virtual Displacement

$$= \int_V \rho \boldsymbol{a} \cdot \delta \boldsymbol{u}\, dV + \int_V \boldsymbol{\sigma} \cdot \nabla \delta \boldsymbol{u}\, dV$$

Acceleration

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- MPM is a Petrov-Galerkin Method - or two basis sets for expansion
  - Expand body force, acceleration, and stress in particle basis
  - Expand virtual displacement in grid basis

$$f(\boldsymbol{x}) = \sum_p f_p \chi_p(\boldsymbol{x})$$

$$\delta \boldsymbol{u} = \sum_i \delta \boldsymbol{u_i} N_i(\boldsymbol{x})$$

- Leads to MPM Equation on the background grid

Nodal Momenta

Nodal Forces

$$\frac{d\boldsymbol{p}_i^{(n)}}{dt} = \boldsymbol{f}_i^{(n)} + \boldsymbol{f}_{i,T}^{(n)}$$

Kirchoff Stress

MPM Shape Functions

$$\boldsymbol{f}_i^{(n)} = \sum_p \left(-m_p \frac{\boldsymbol{\tau}_p^{(n)} \cdot \boldsymbol{G}_{ip}^{(n)}}{\rho_0} + m_p S_{ip}^{(n)} \boldsymbol{b}_p + \boldsymbol{F}_p^{(n)} S_{ip}^{(n)} \right)$$

$$\boldsymbol{f}_{i,T}^{(n)} = \int_{S_T} \boldsymbol{N}_i(\boldsymbol{x}) \boldsymbol{T} \, dS$$

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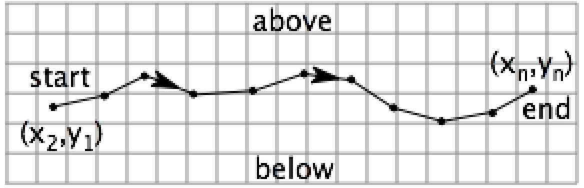
Fractures in MPM

CRAMP is MPM extended to handle explicit fractures (Nairn, 2003)



Fractures represented by a series of line segments with endpoints represented by massless material points

- Fracture particles influence the velocity field in the grid.
- Each node can have multiple velocity fields.
- Any number of fractures is possible
- Mesh-free path and propagation
- Robust modeling (compared to other particle methods) thanks to the grid

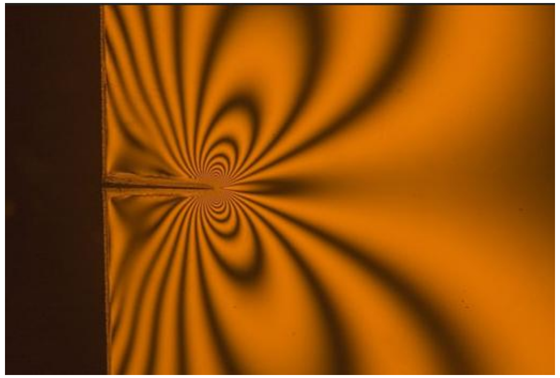
Fracture Mechanics

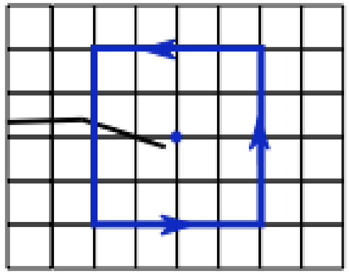
- Elastic fracture mechanics is used to model material failure and fracture propagation

- The energy release rate *G* involved in the balance of energies in fracturing media is used to compute stress singularities and predict fracture propogation

- The fracture grows when $G > G_{critic}$

- HF propagation criterion: direction of maximum energy release rate





G = J Integral

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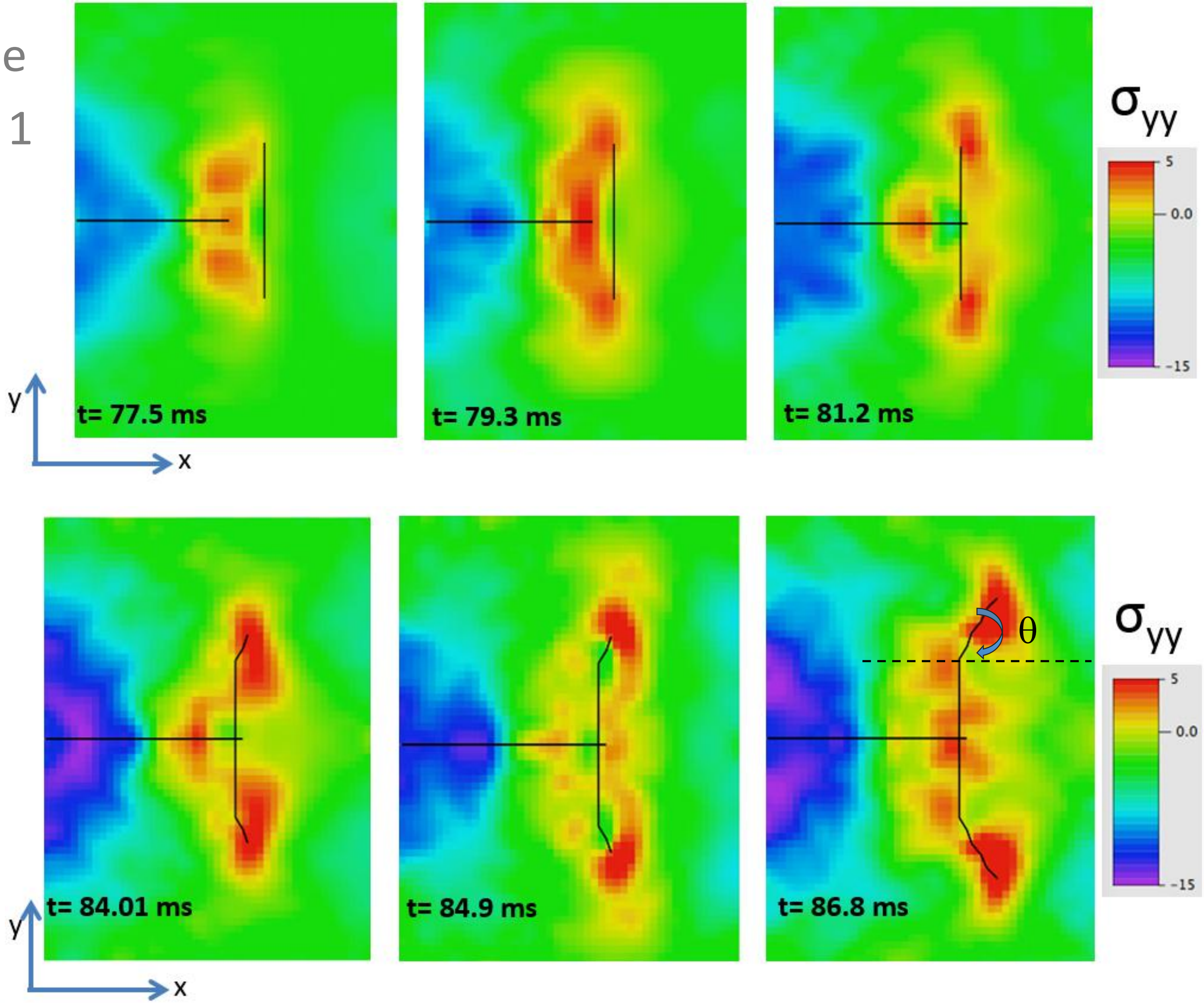
NF Propagation using Energy Criterion

Case

A = 1



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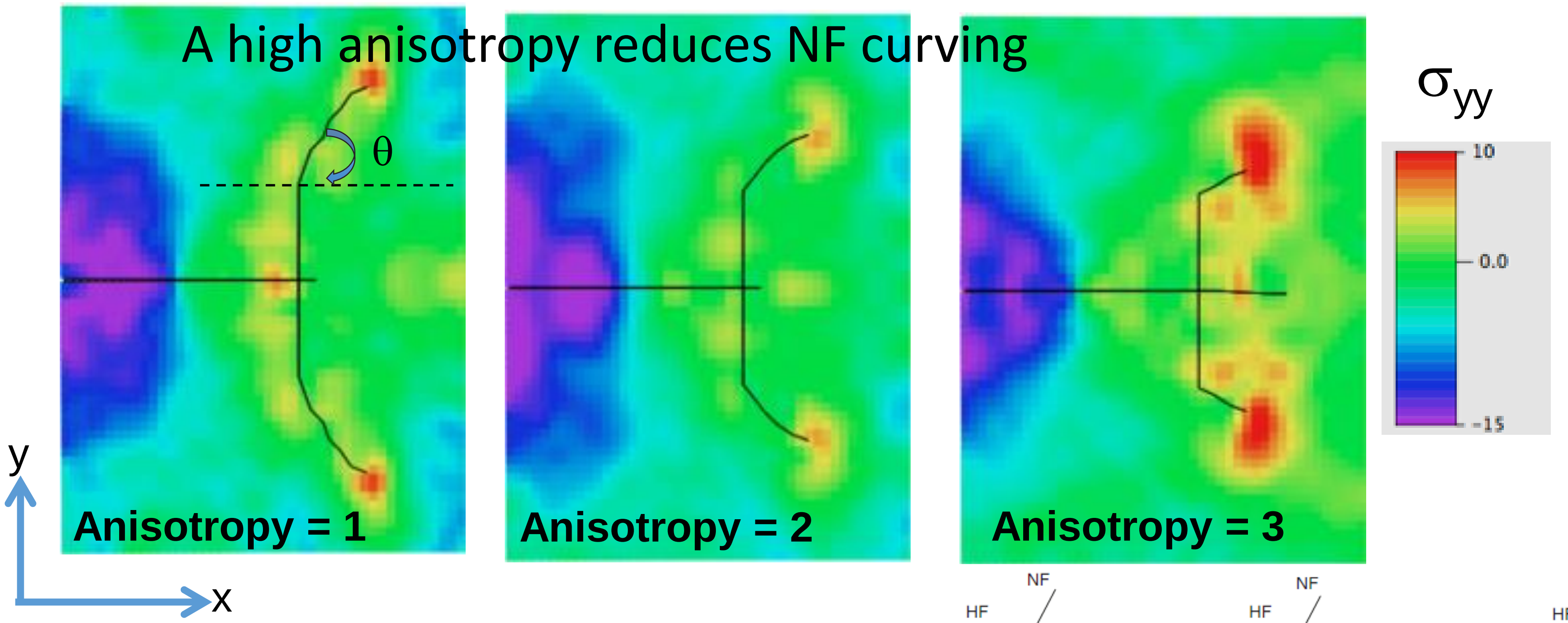
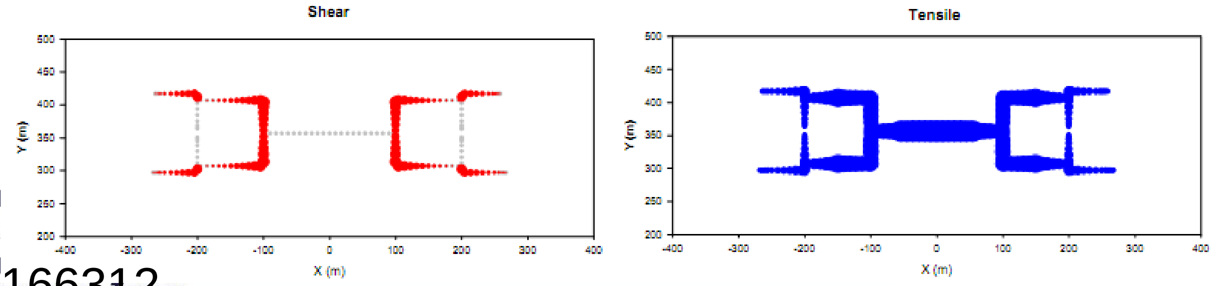
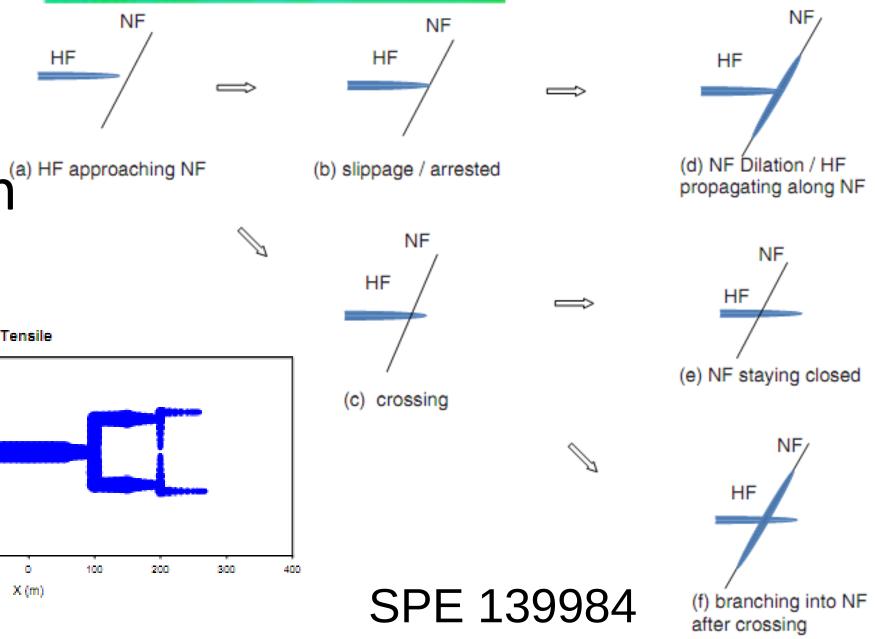
Effect of stress anisotropy on NF curving



Other software tend to have propagation rules that are only seen in High anisotropy situations



SPE 166312



SPE 139984

A Marcellus case study

http://ny.water.usgs.gov/projectsummaries/CP30/Marcellus_Presentation_Williams.pdf

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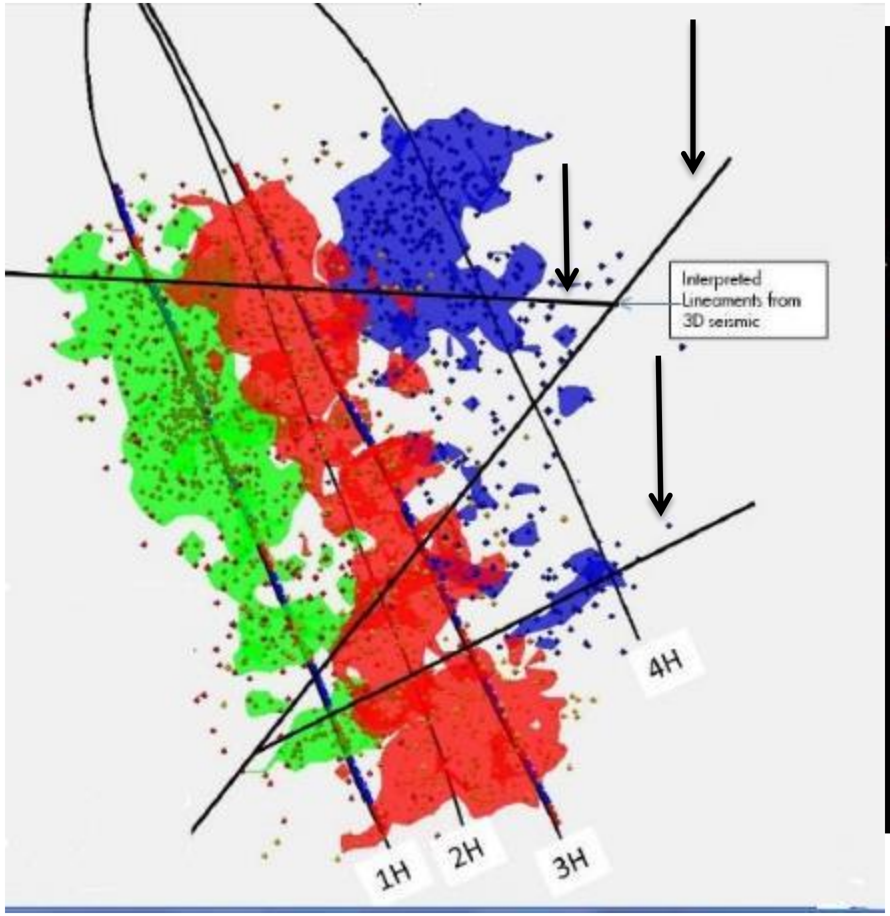
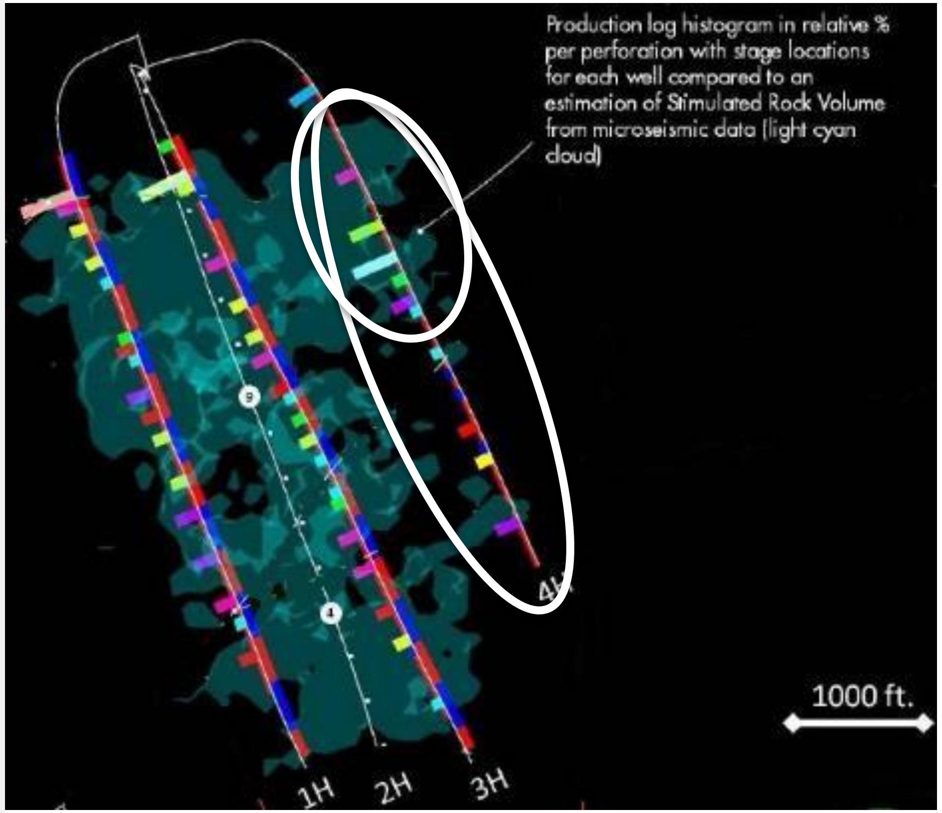
A complex Marcellus microseismic



MS events & interpreted seismic lineaments



Production logs

URTeC 1577009, 2013

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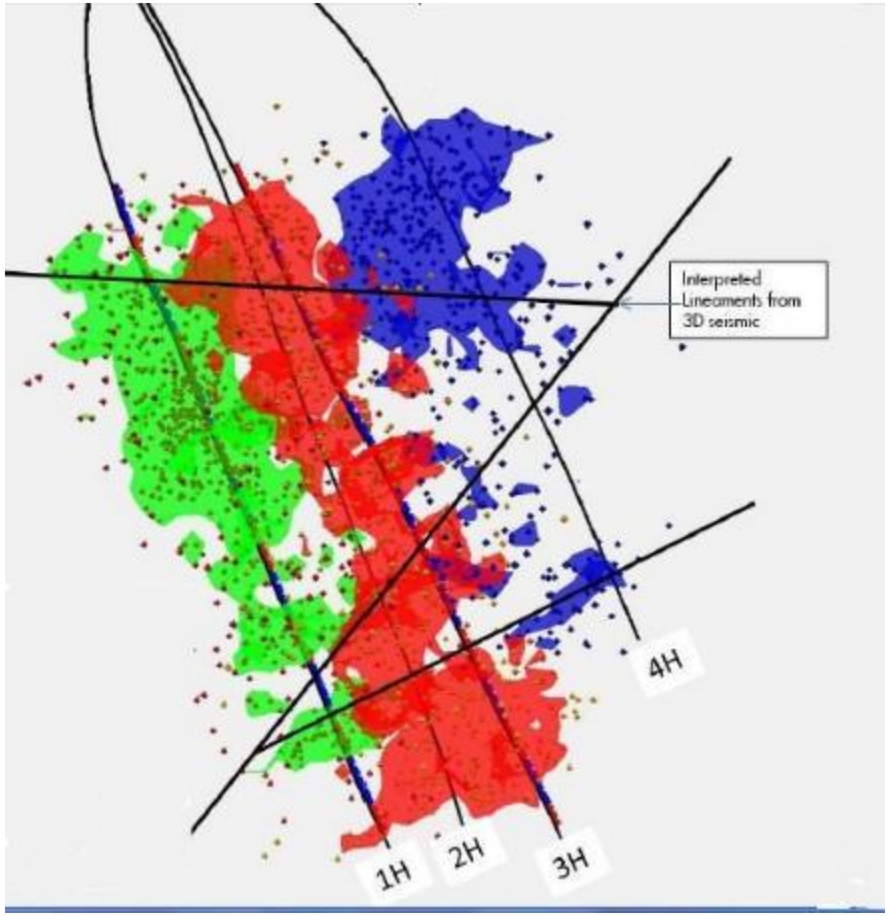
Geophysics to get natural fractures



MS events & interpreted seismic lineaments

Seismically derived curvature as a proxy for the natural fractures

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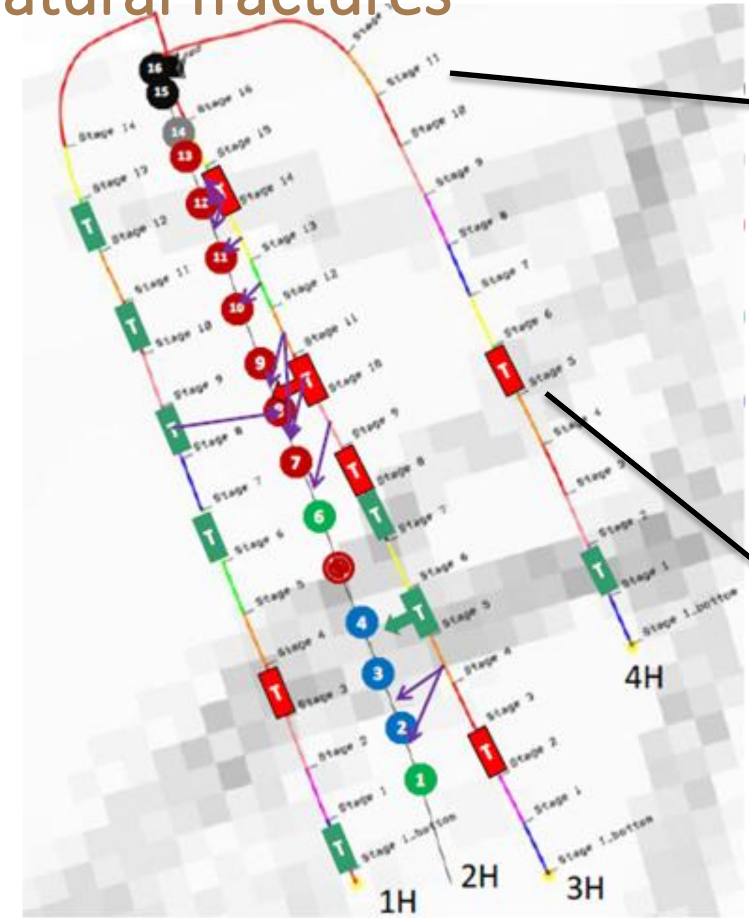
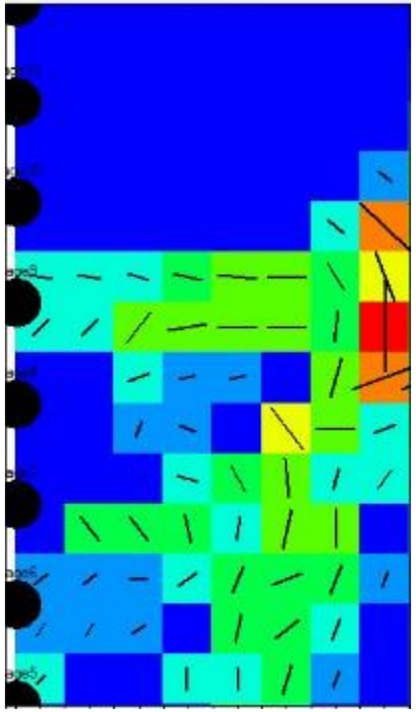
Equivalent Fracture Model (EFM) derived from fault attribute used as proxy for natural fractures



Fault attribute (Gray color) and the wells along with their frac stages

Stage 11

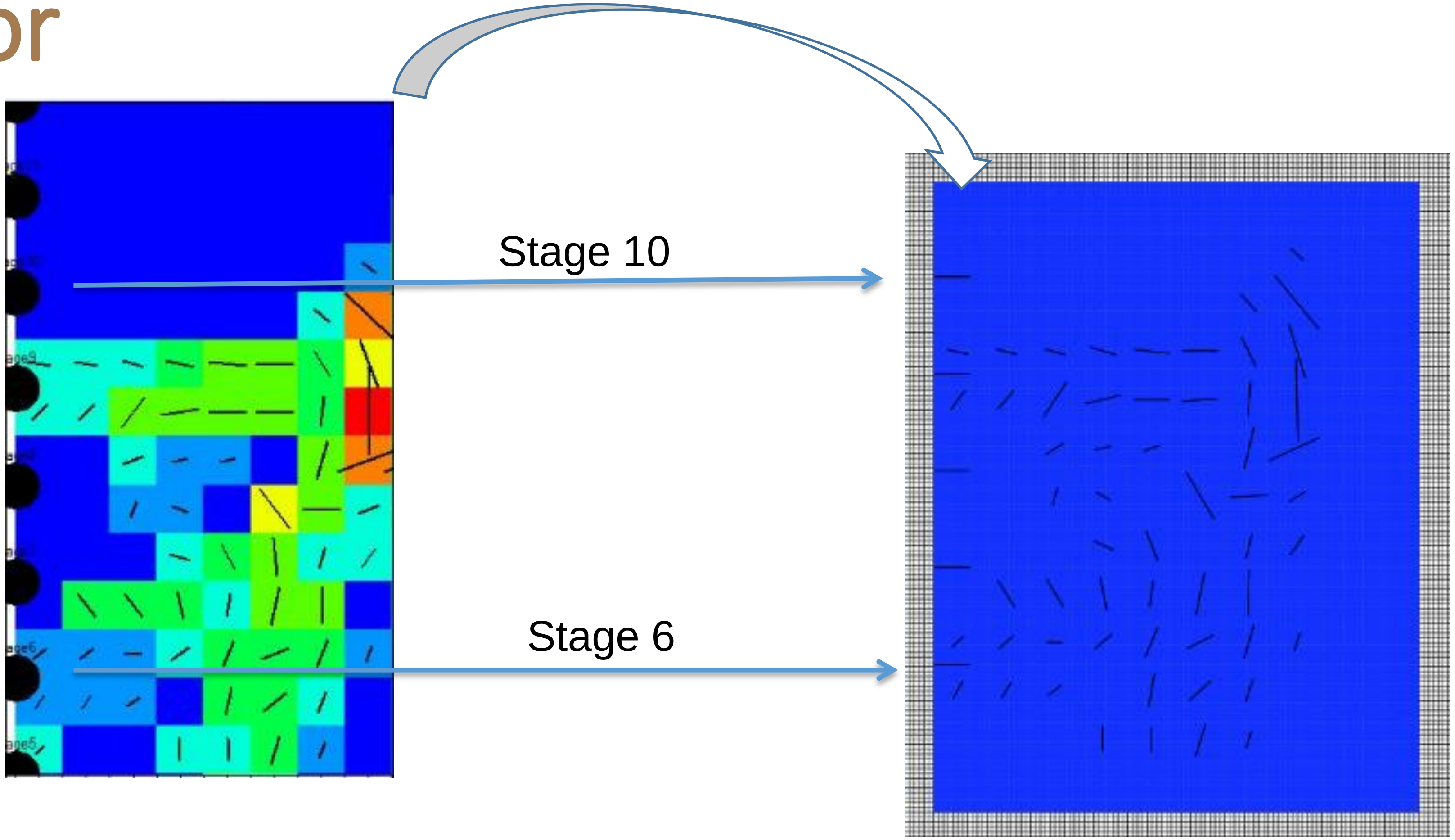
Stage 5



Equivalent Fracture Model (EFM)

SPE 167801, 2014

Importing the EFM in the geomechanical simulator



EFM Model

MPM Geomechanical model

SPE 167801, 2014

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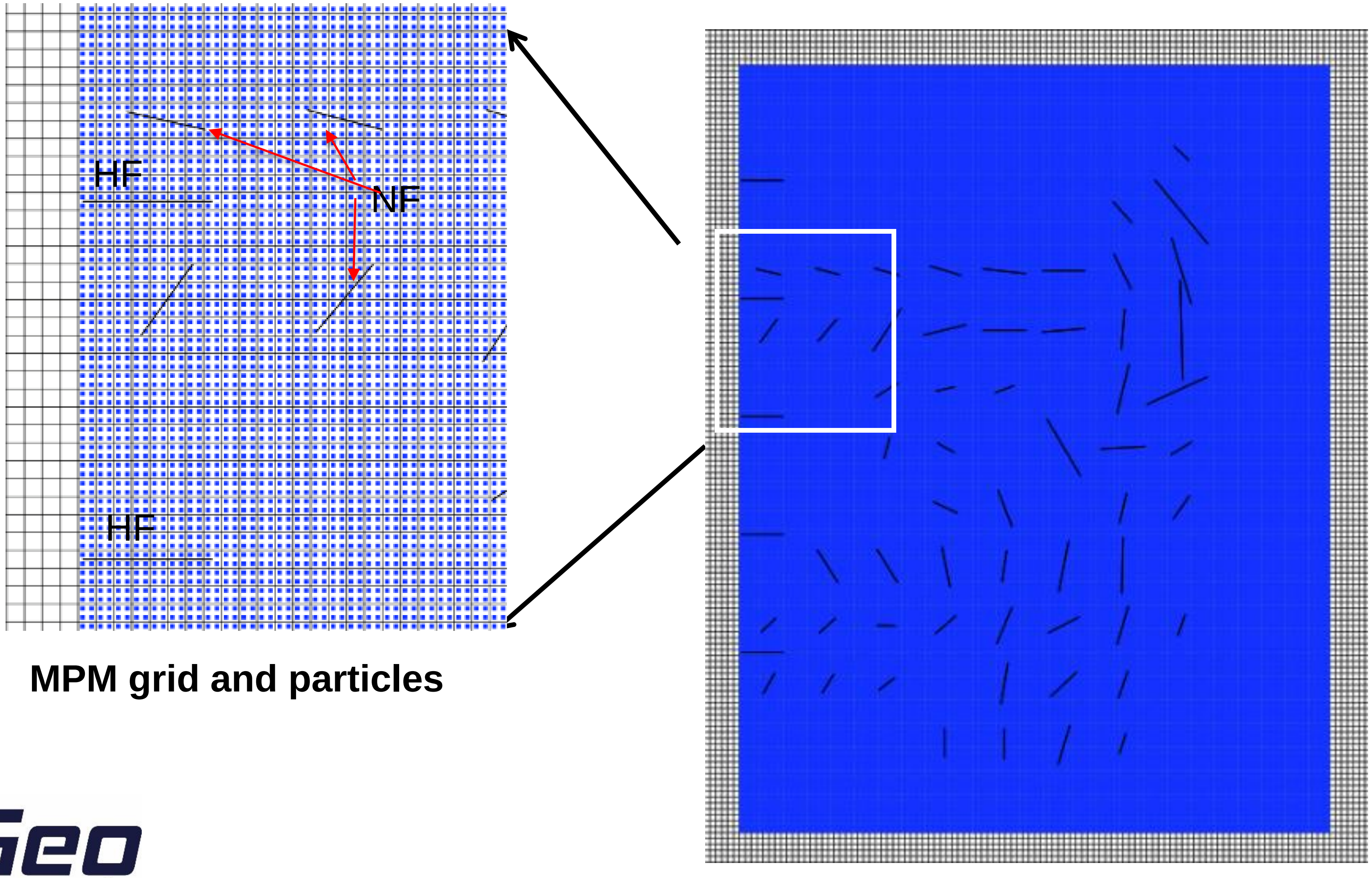
Material Point Method (MPM) discretization



MPM grid and particles

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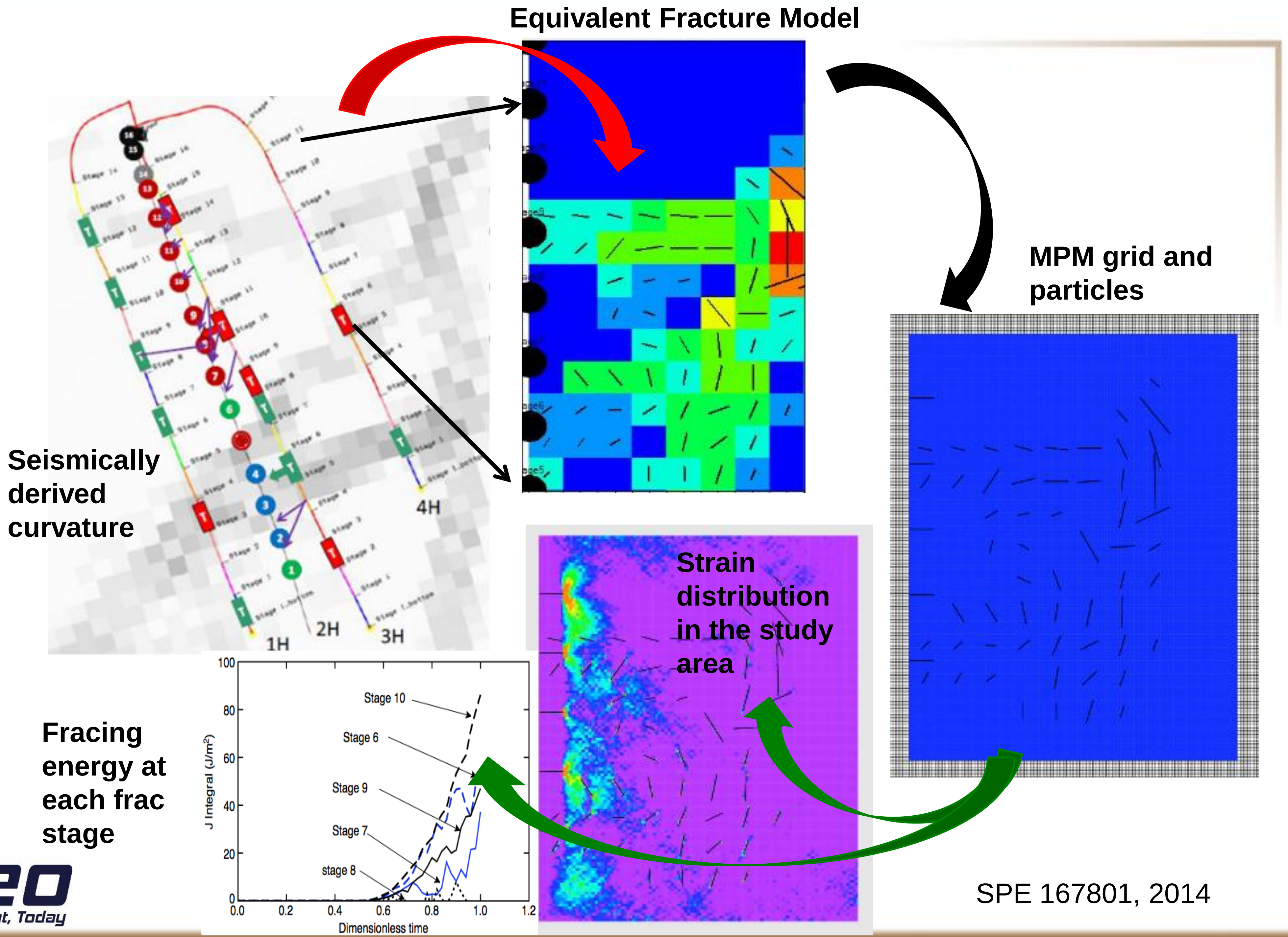
3G Workflow



SPE 167801, 2014

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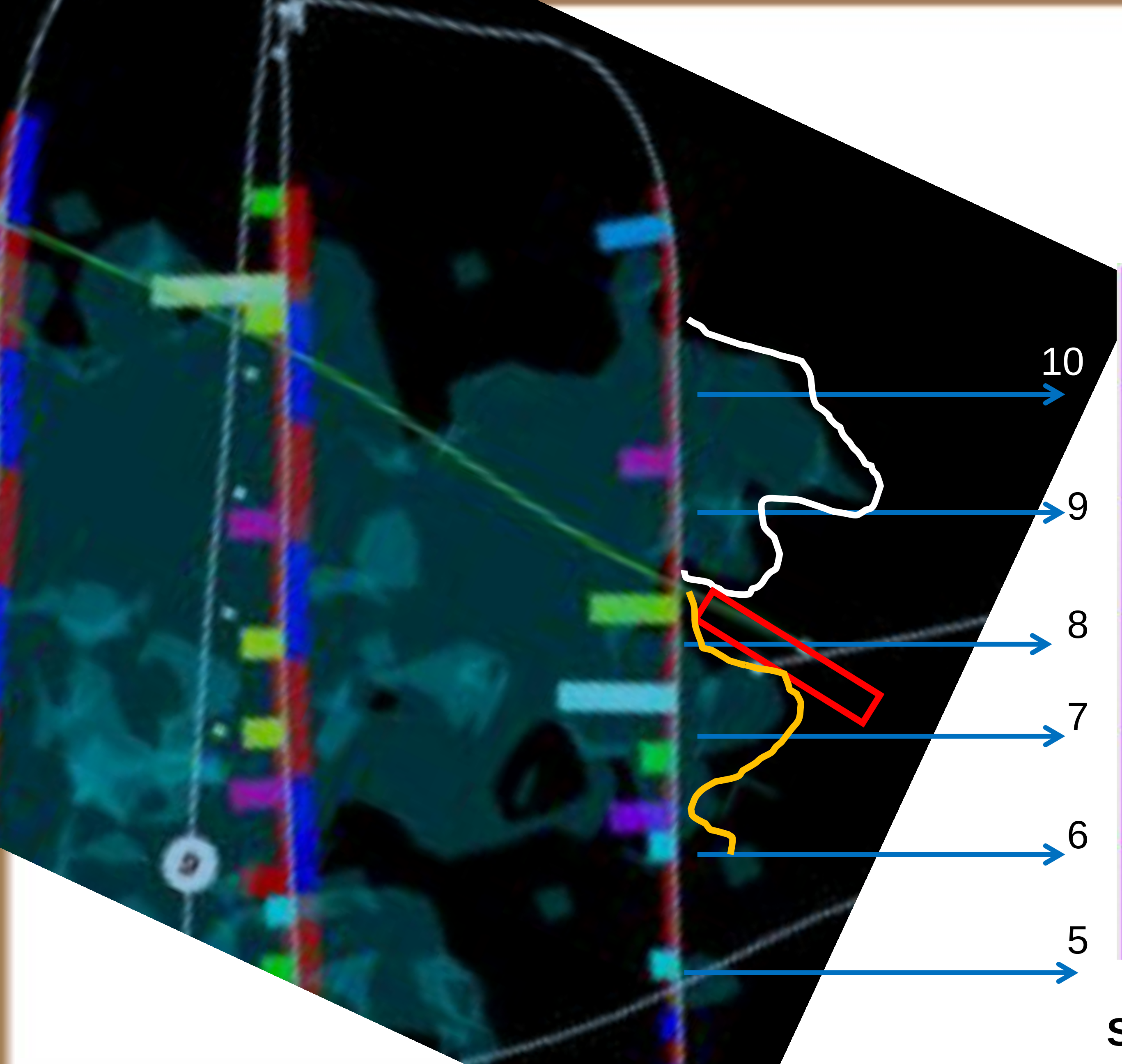
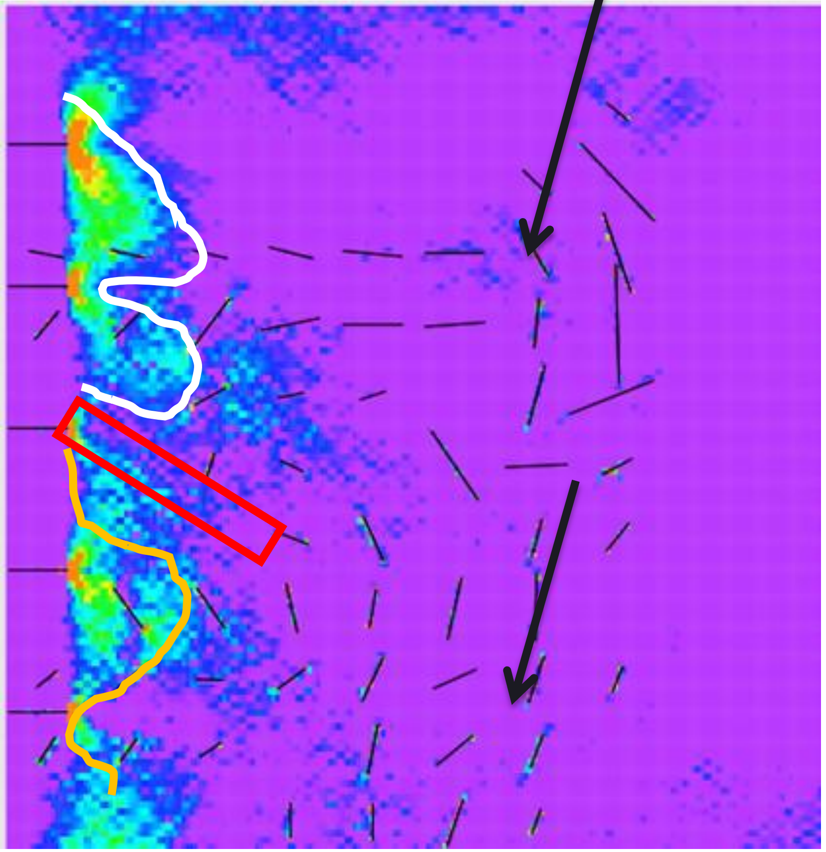
Results



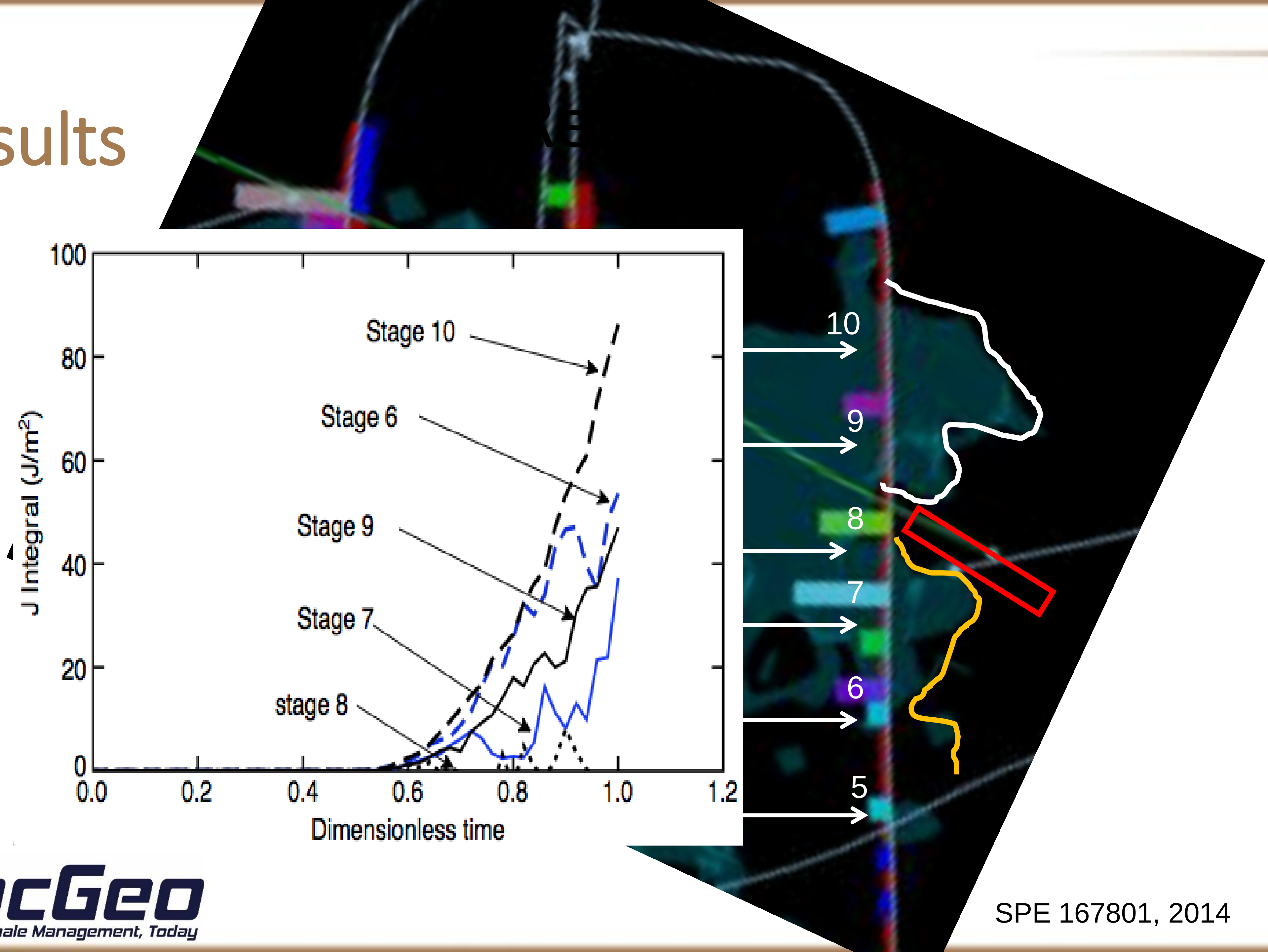
MS Events &
production log



Strain distribution in the study area

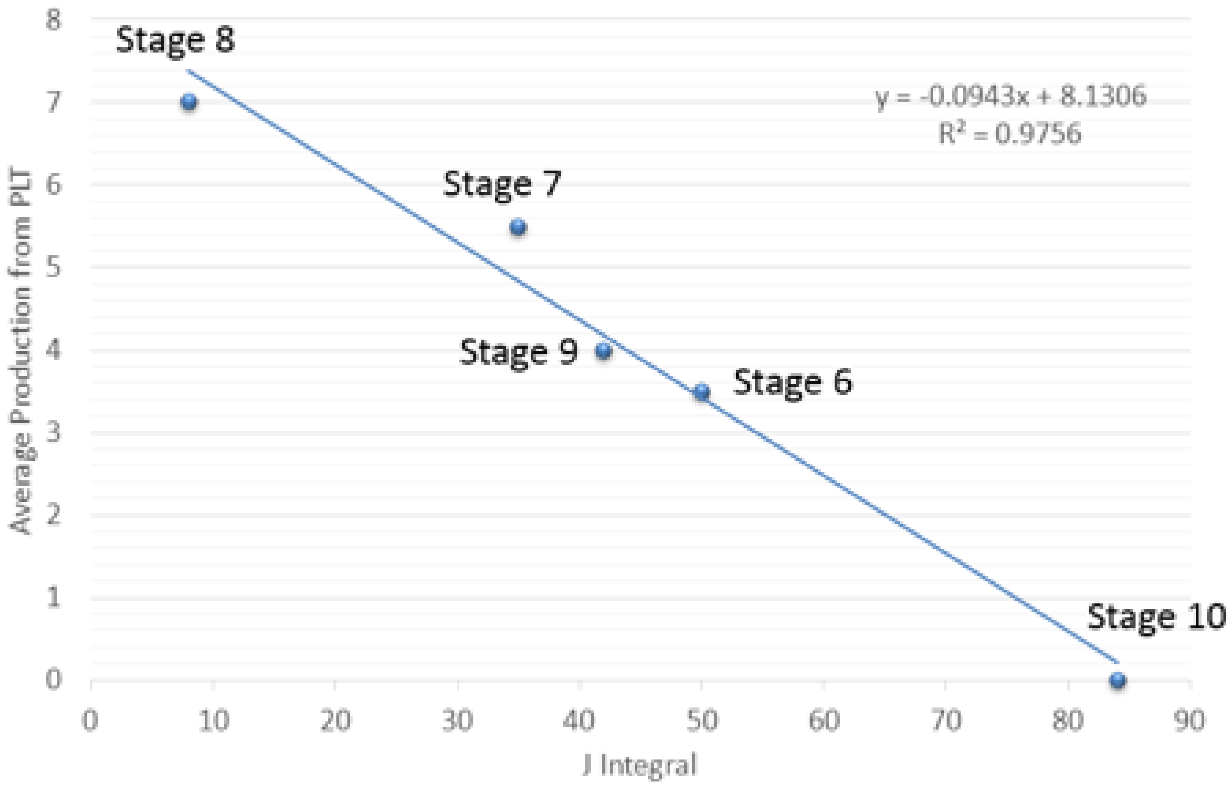
SPE 167801, 2014

Results



SPE 167801, 2014

Correlation between fracing energy and frac stage performance



URTeC 1923762, 2014

- J Integral & PLT are highly correlated in the Marcellus well 4H
- J Integral as a proxy to the PLT in the Marcellus well 4H

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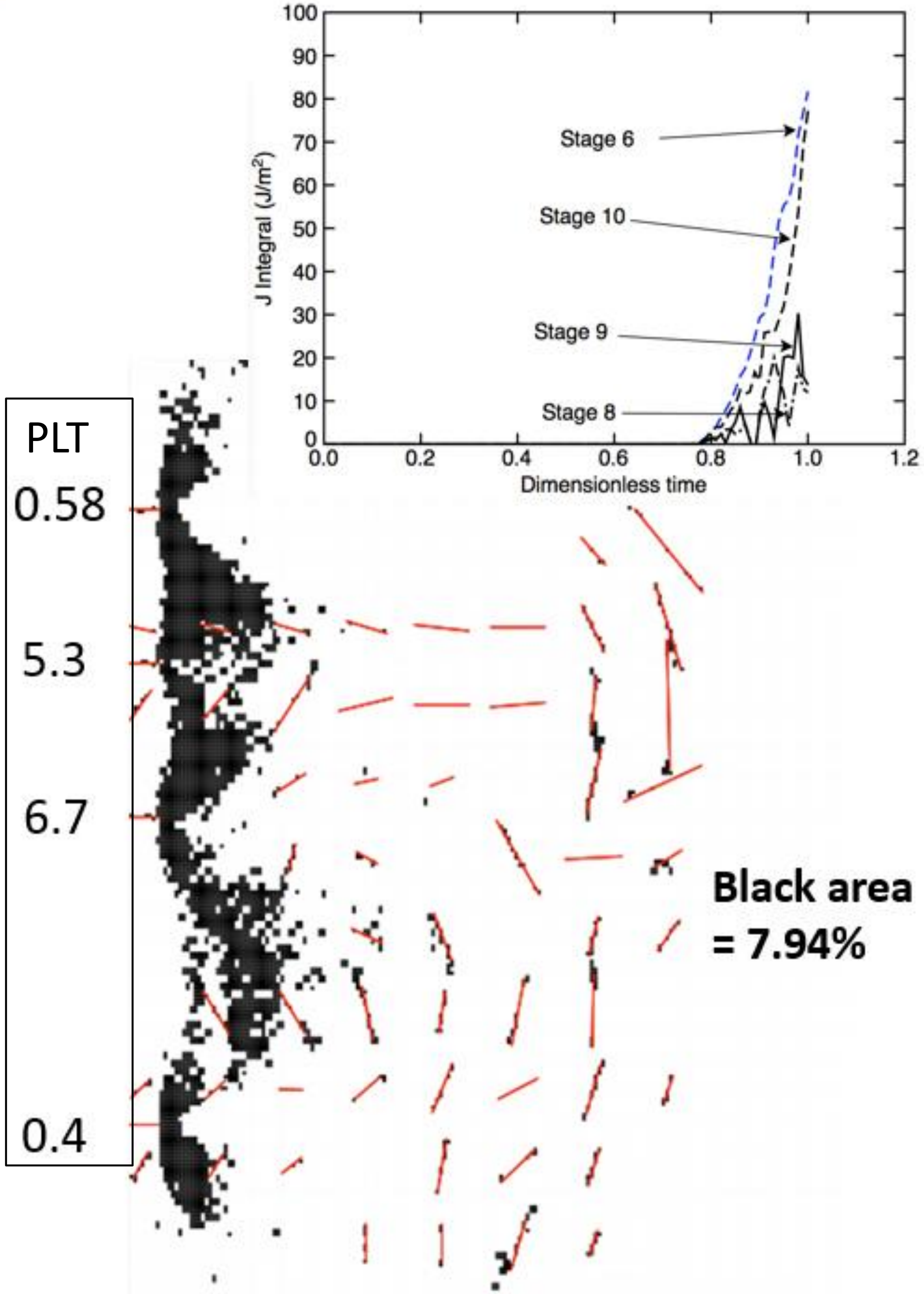
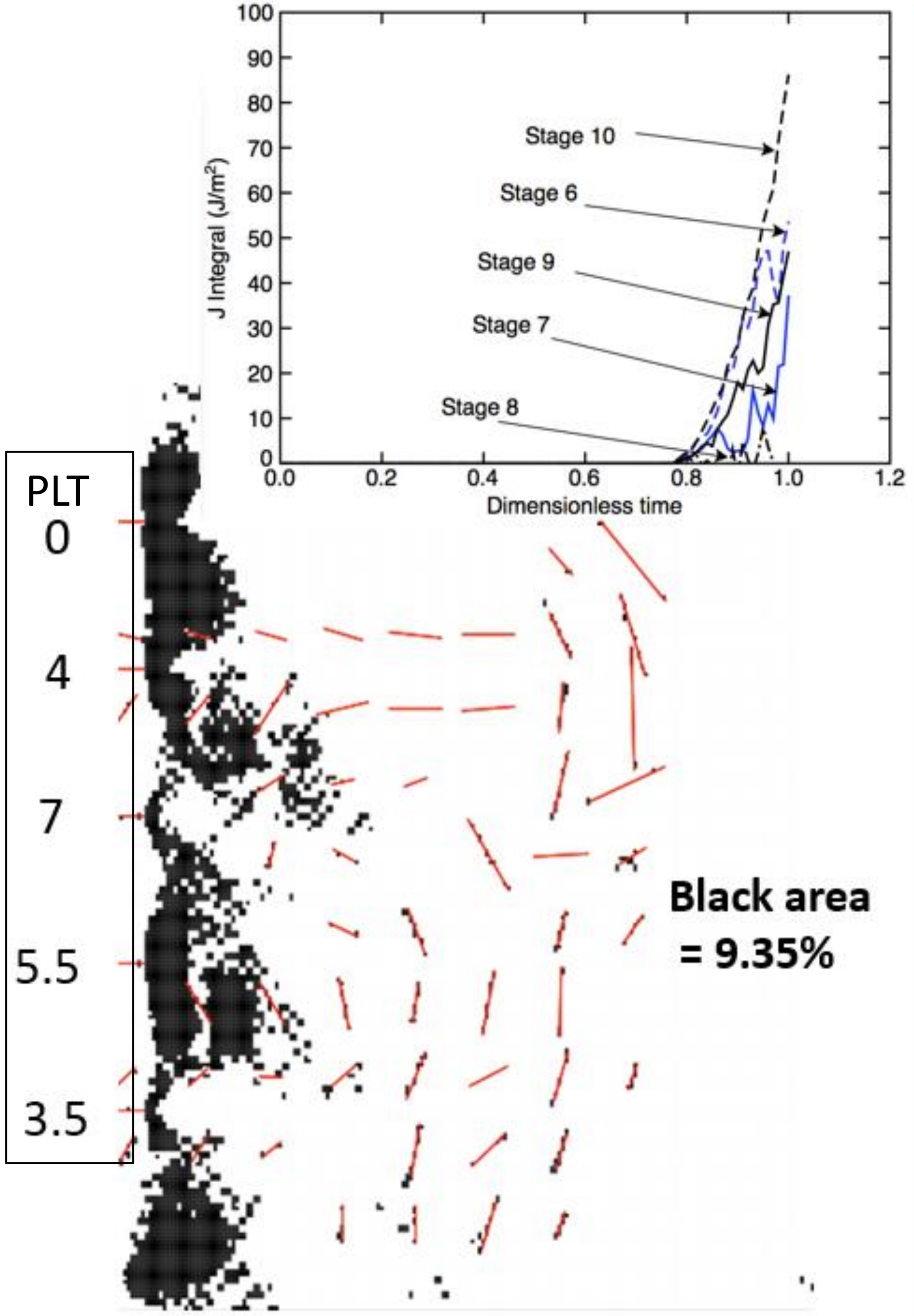


Without Frac Stage 7



All Frac Stages

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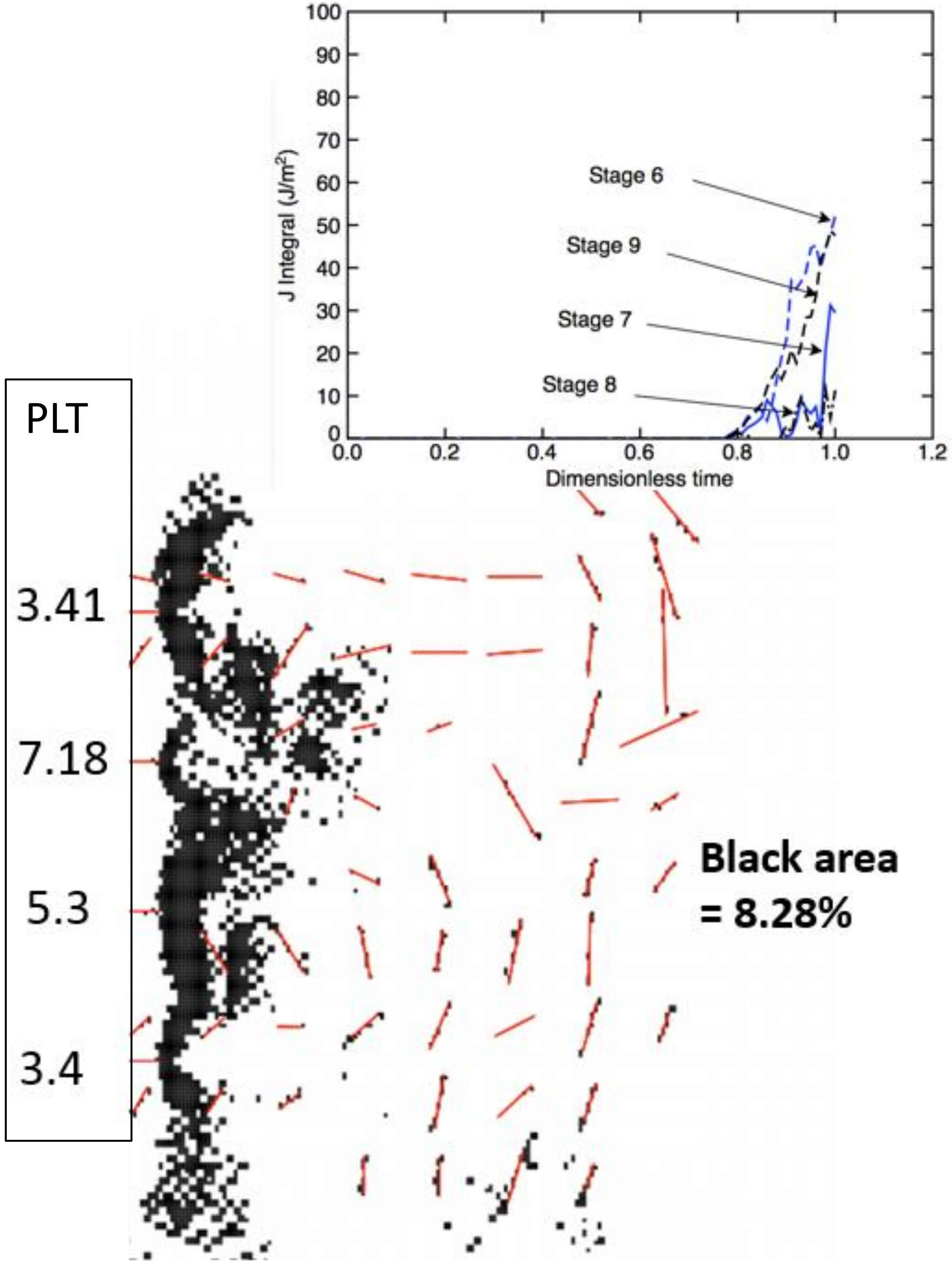
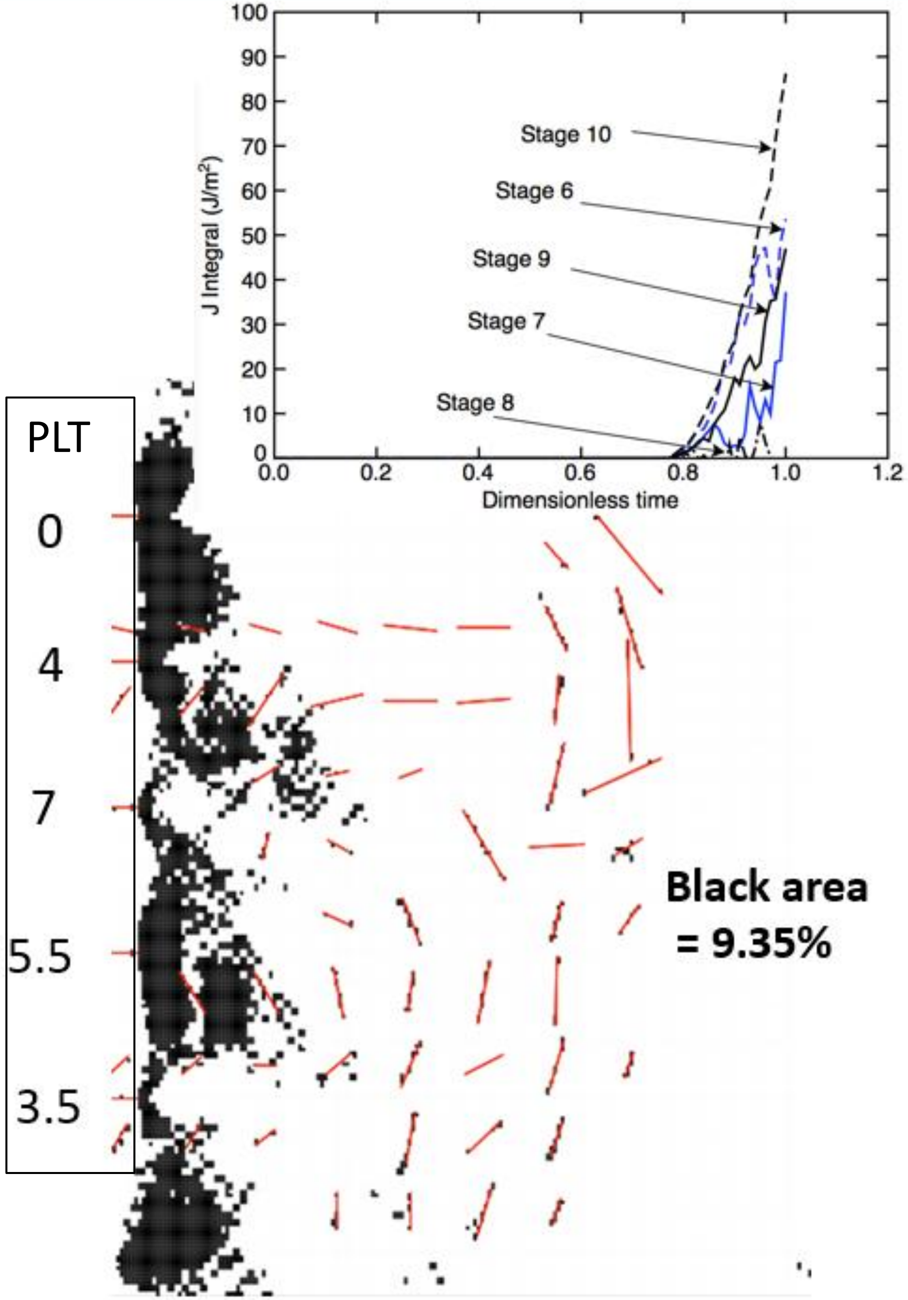


Without Frac Stage 10



All Frac Stages

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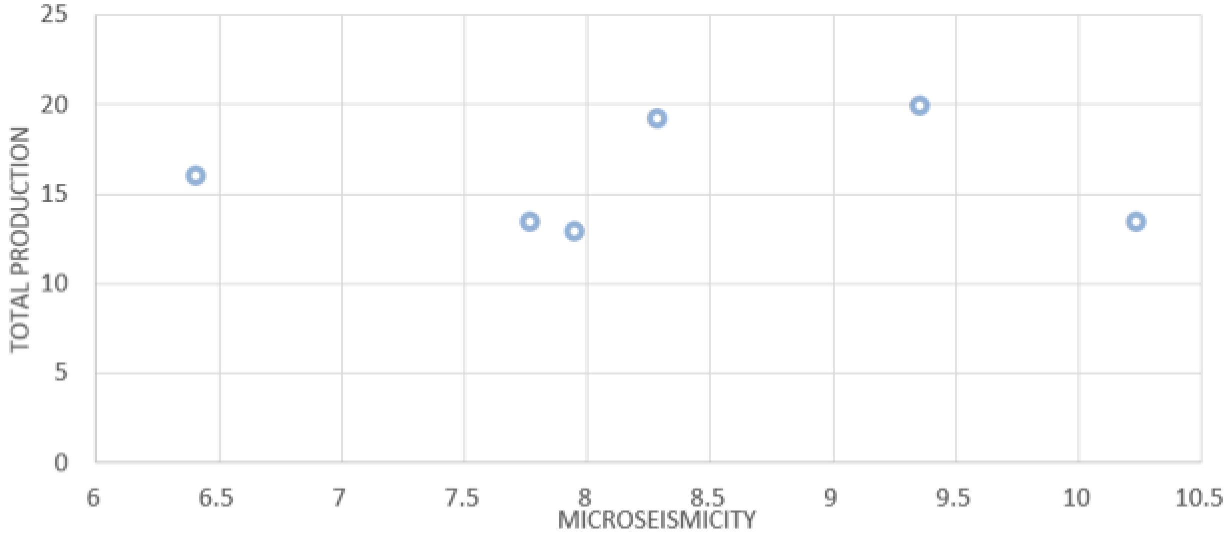
Completion design: predicted PLT and MS

Completion	Stage 6 PLT	Stage 7 PLT	Stage 8 PLT	Stage 9 PLT	Stage 10 PLT	Total production	Microseismicity
All frac stages	3.5	5.5	7	4	0	20	9.35
No Frac stage 6	NA	5.1	6.24	4.17	0.58	16.09	6.4
No Frac stage 7	0.4	NA	6.7	5.3	0.58	12.98	7.94
No frac stage 8	3.88	4.35	NA	5.3	0	13.53	10.23
No frac stage 9	3.88	4.35	5.3	NA	0	13.53	7.76
No frac stage 10	3.4	5.3	7.18	3.41	NA	19.29	8.28



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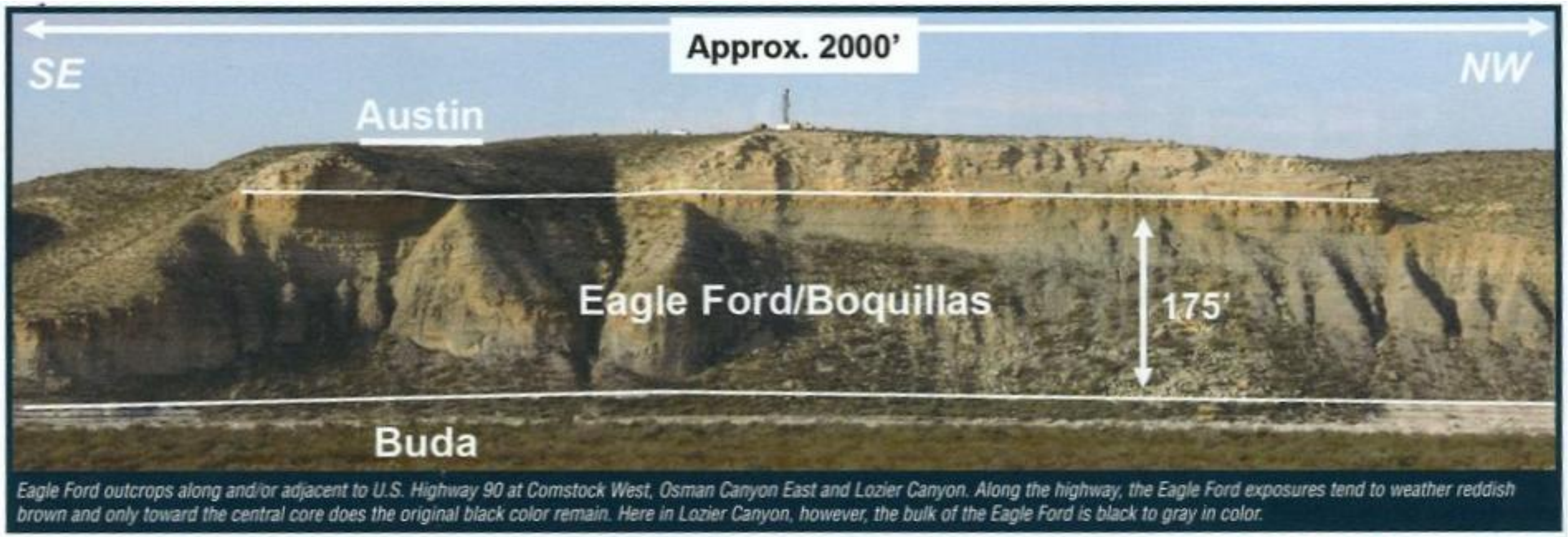
An Eagle Ford case study



AAPG Explorer 2013

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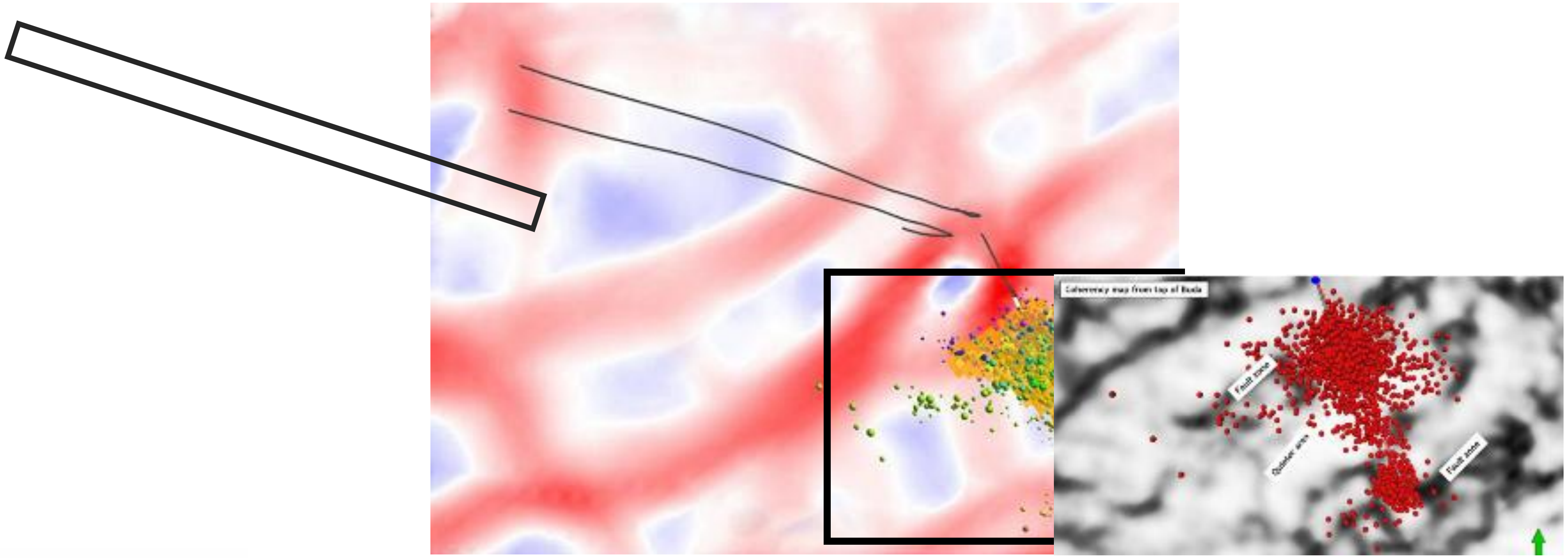
Eagle Ford case study (URTeC 1923762)

- Validation on the well south east
- Prediction on the well northwest



Large scale curvature

Coherency attribute

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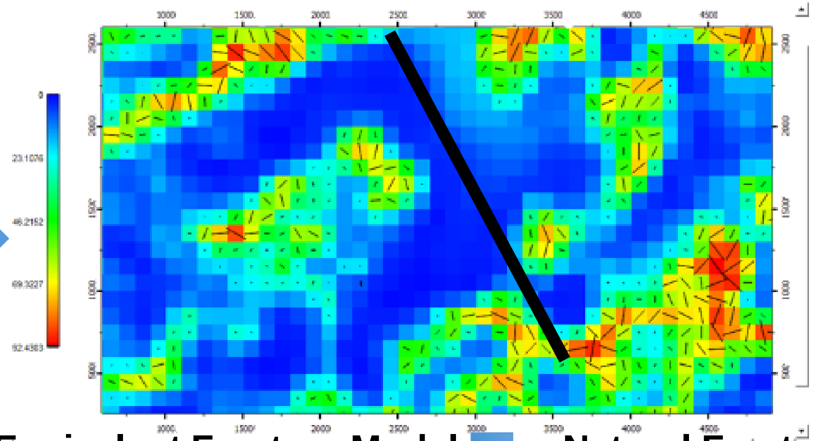
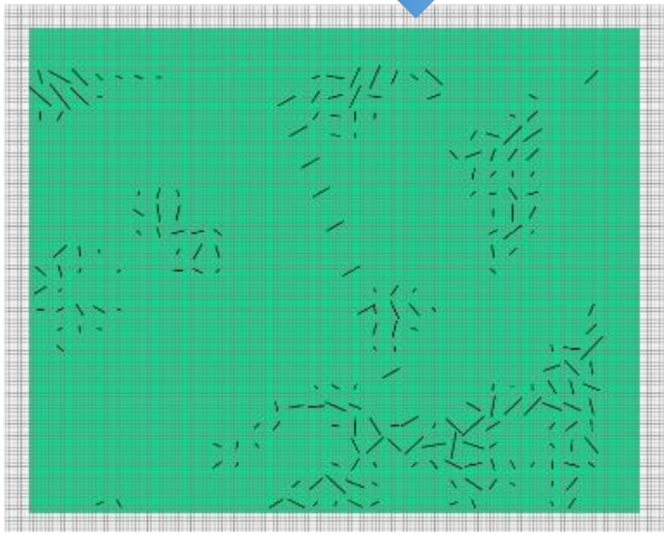
Geomechanical workflow

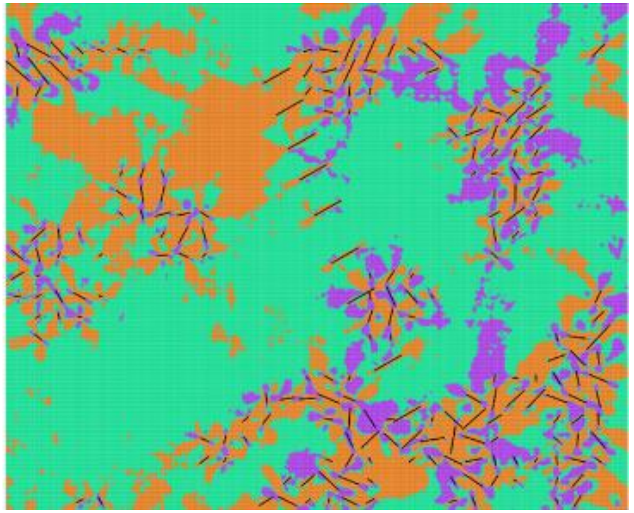
seismically derived coherency: structural attribute



Equivalent Fracture Model: Natural Fractures



MPM grid & particles with HF and NF network



Differential stress field after application of regional stress

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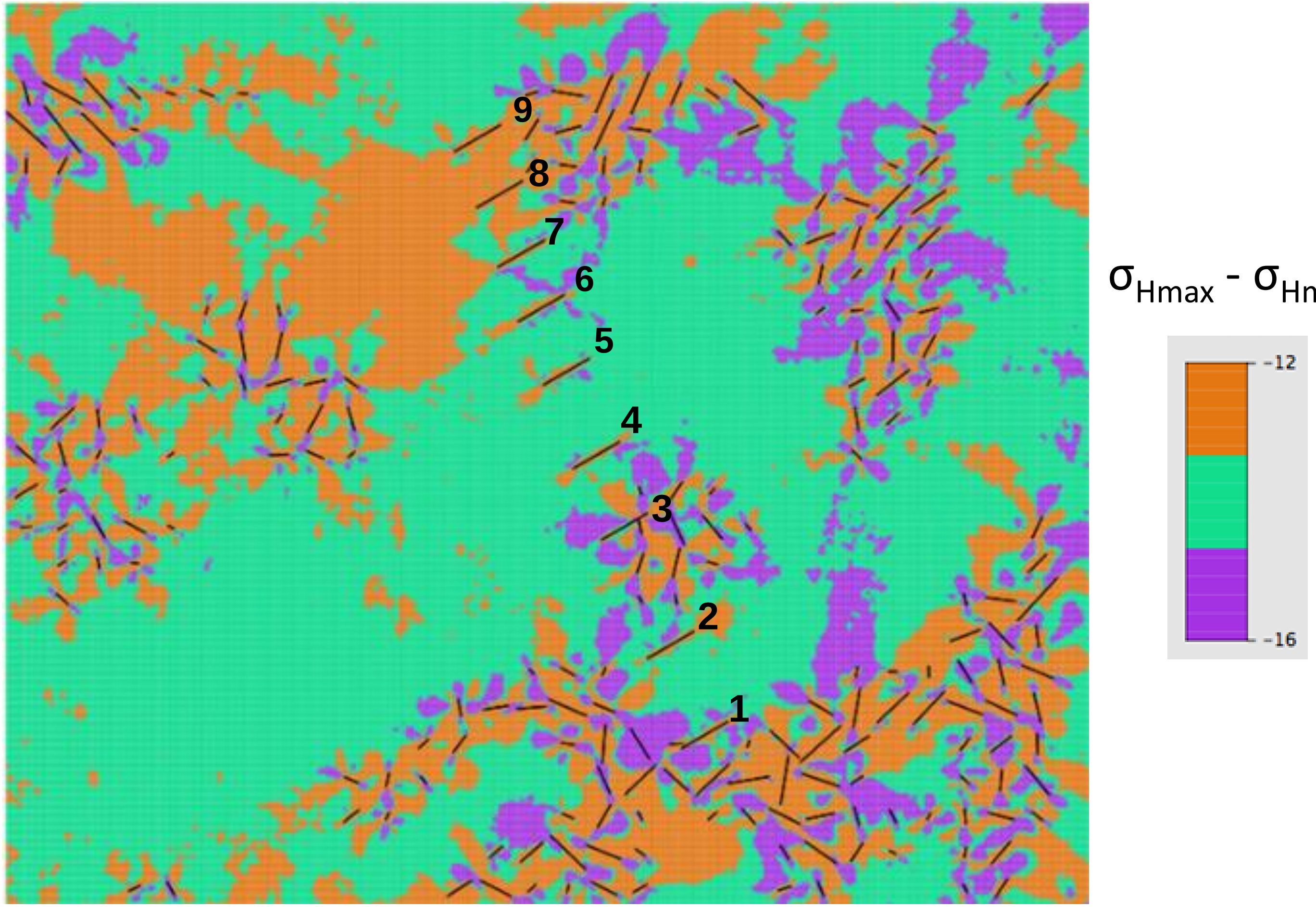
Differential stress created by the fractures



URTeC 1923762, 2014

- Differential stress field is not uniform
- Frac stages do have different $\sigma_{Hmax} - \sigma_{Hmin}$
- Frac stages near the heel have lower differential stress

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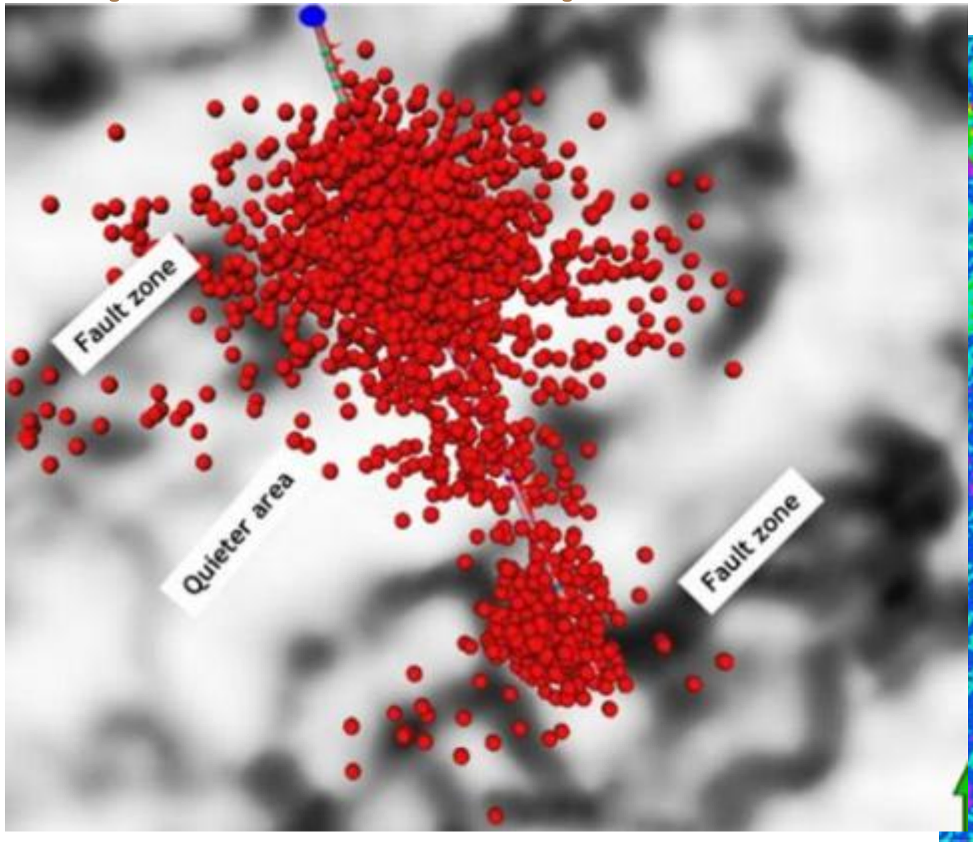
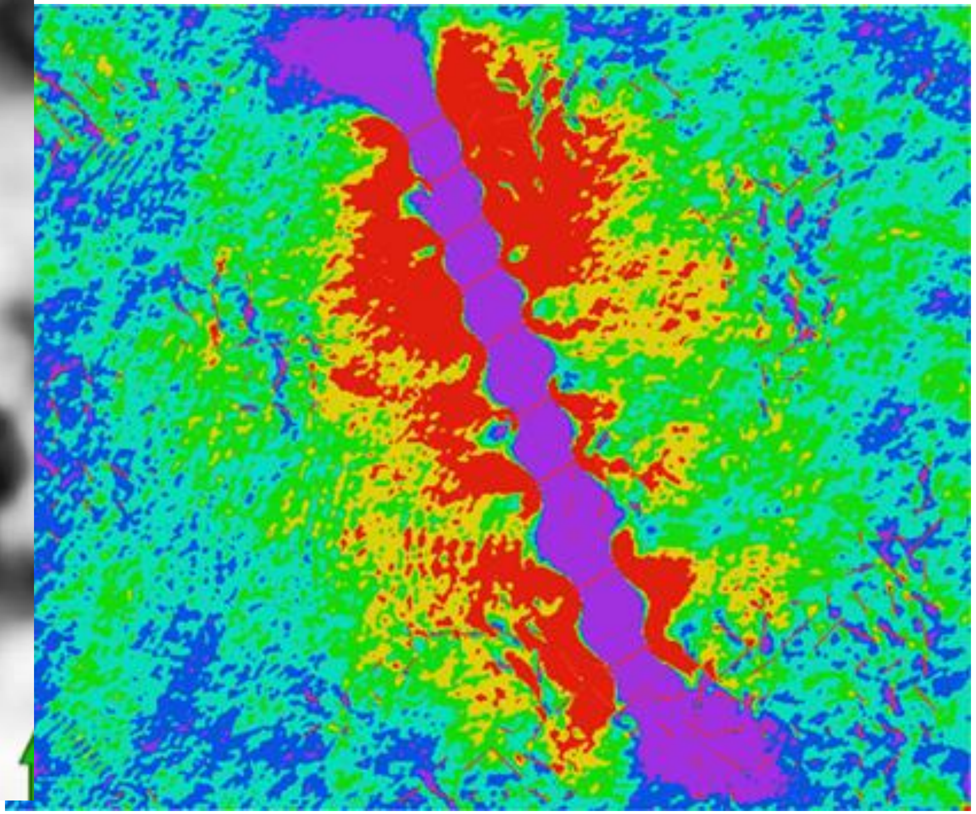
Interpreted vs predicted MS





- The MPM geomechanical workflow able to predict complex microseismicity

URTeC 1923762, 2014

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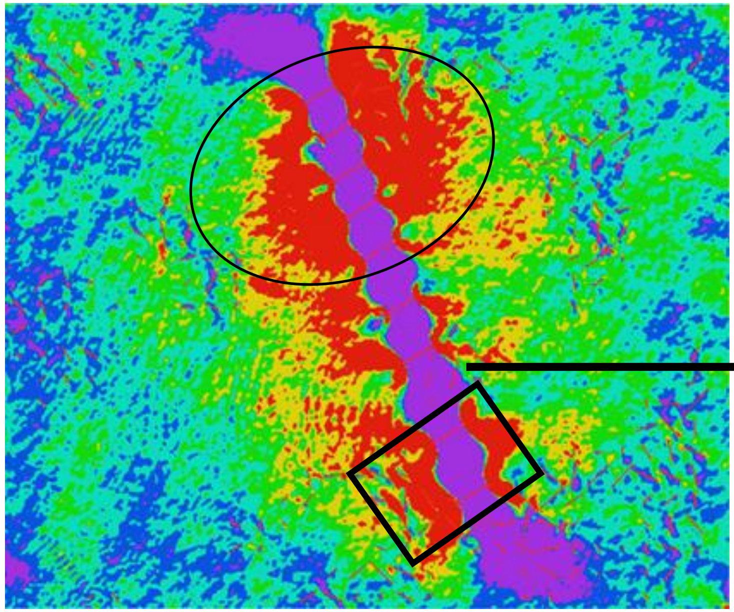
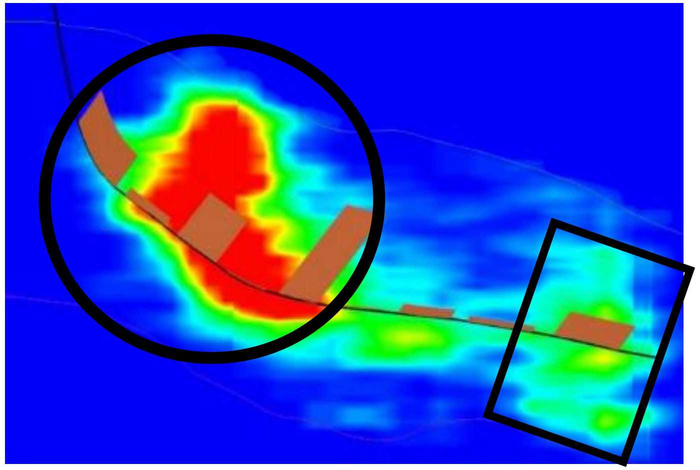
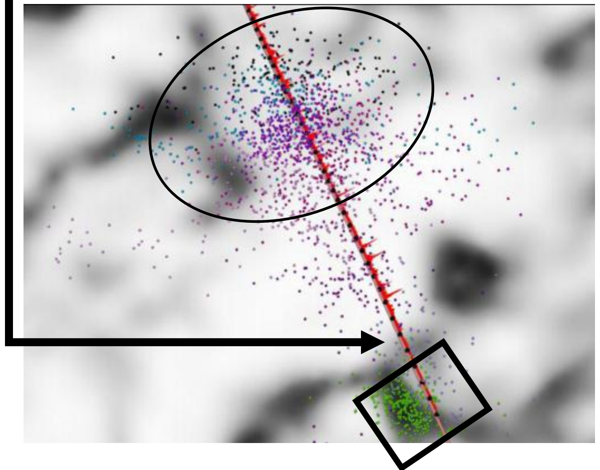
Validation with Tracers



A: Strain in the y direction derived from the geomechanical simulation.



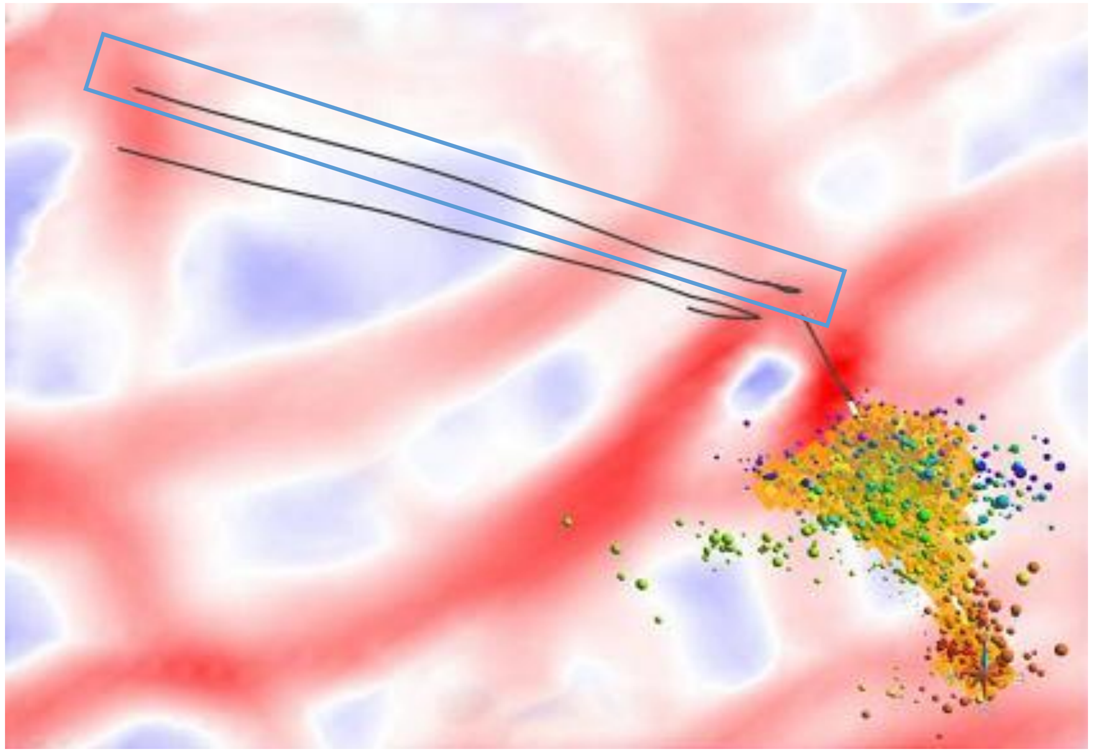
C: Cross section along the wellbore showing the microseismic density and tracer. Meek et al. (2013)



B: Tracers and microseismic event from Diakhate et al. (2015)

- MPM shows the 3 distinguish regions
- The heel is better than the toe and the middle of the well is not performing

Predicting MS in a well that has no MS



Large scale curvature

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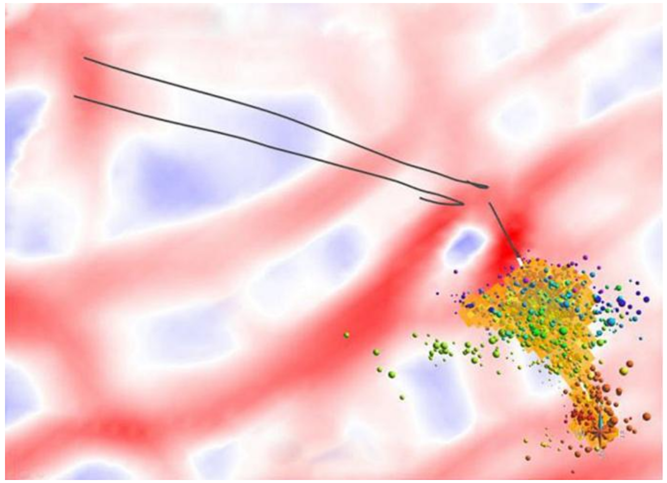
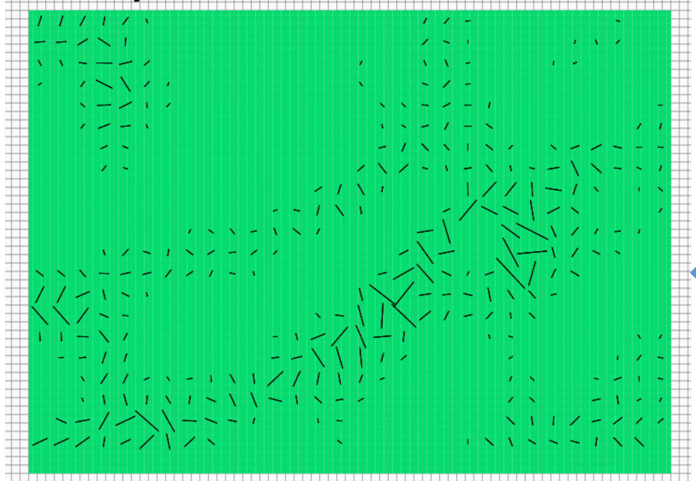
Geomechanical workflow

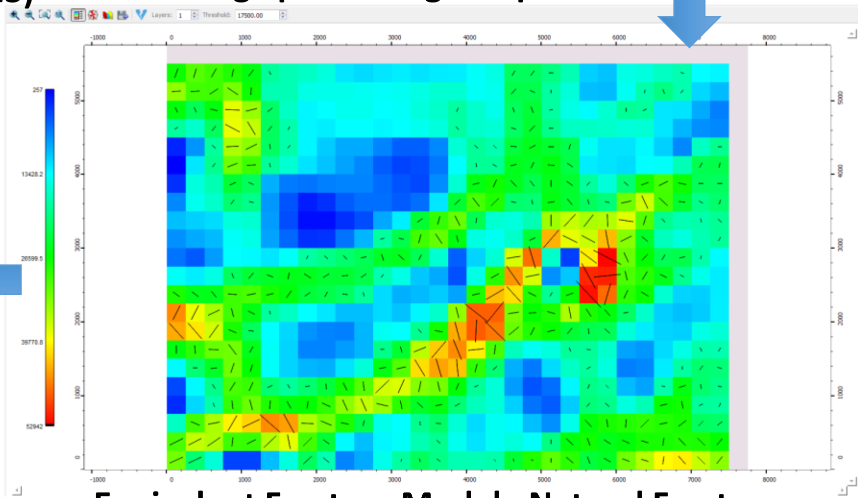


Seismically derived curvature from Meek et al. (2013)

Image processing and pixilation



MPM grid and particles with natural fractures



Equivalent Fracture Model: Natural Fractures

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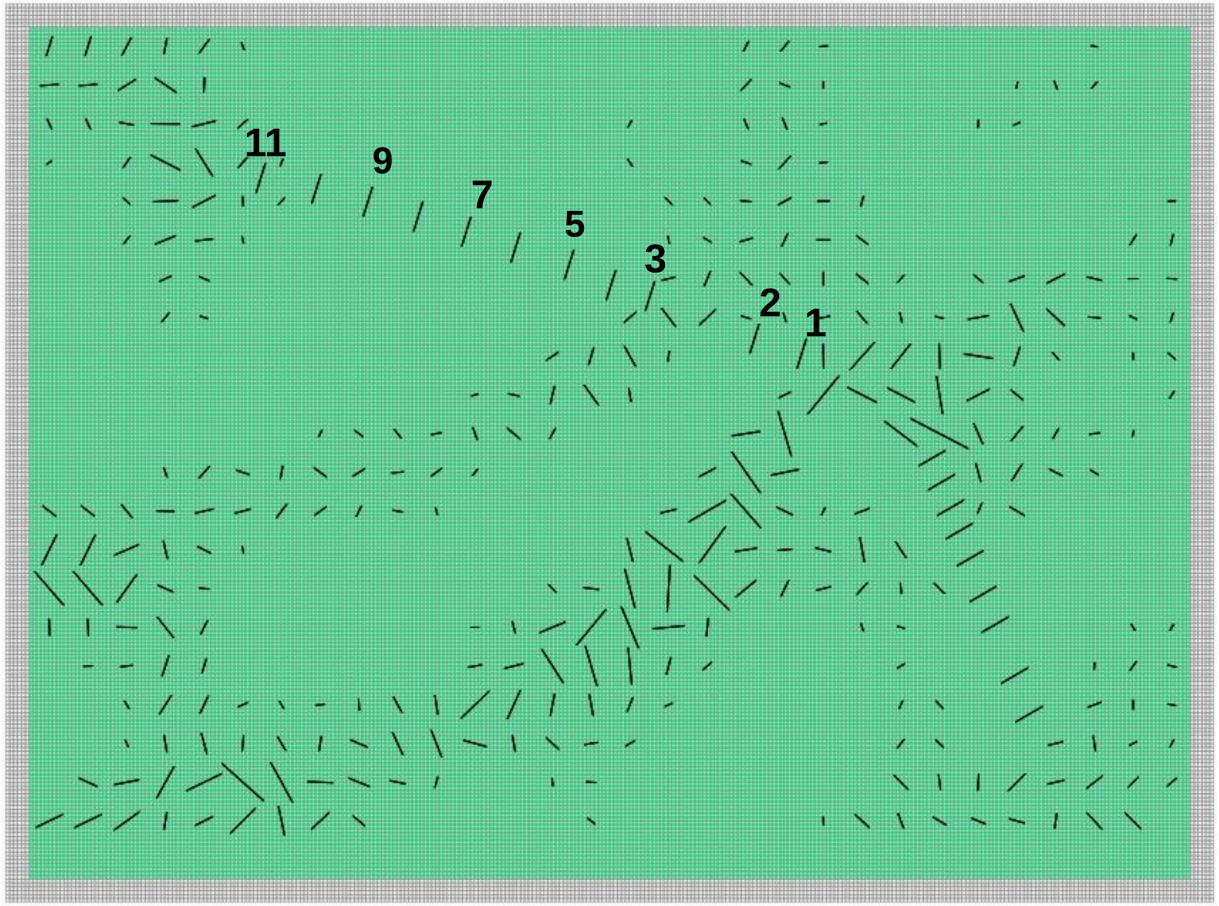
MPM Discretization – grid and particles



- Fracing the NW well with 11 frac stages using and engineered completion
- Large spacing between frac stages 2 & 3 because of high differential stress

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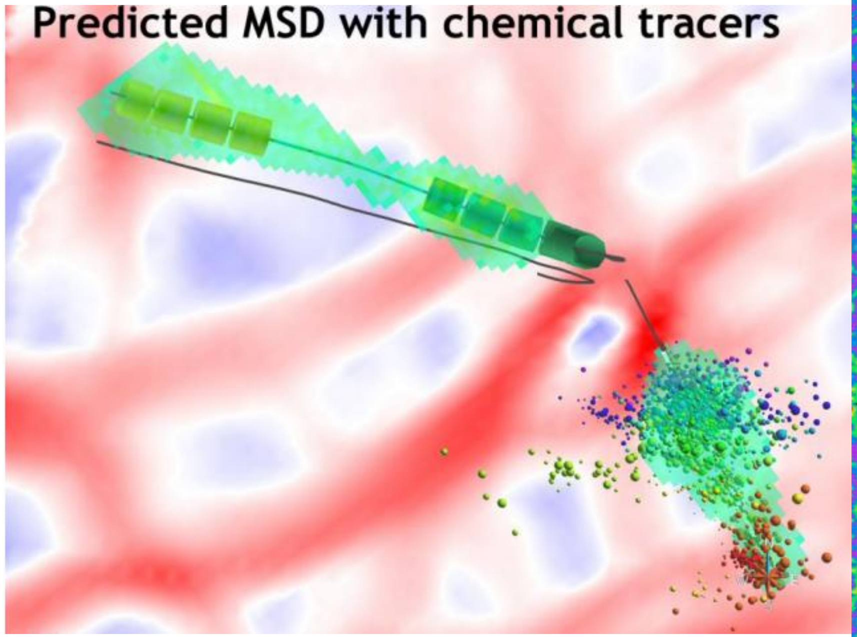
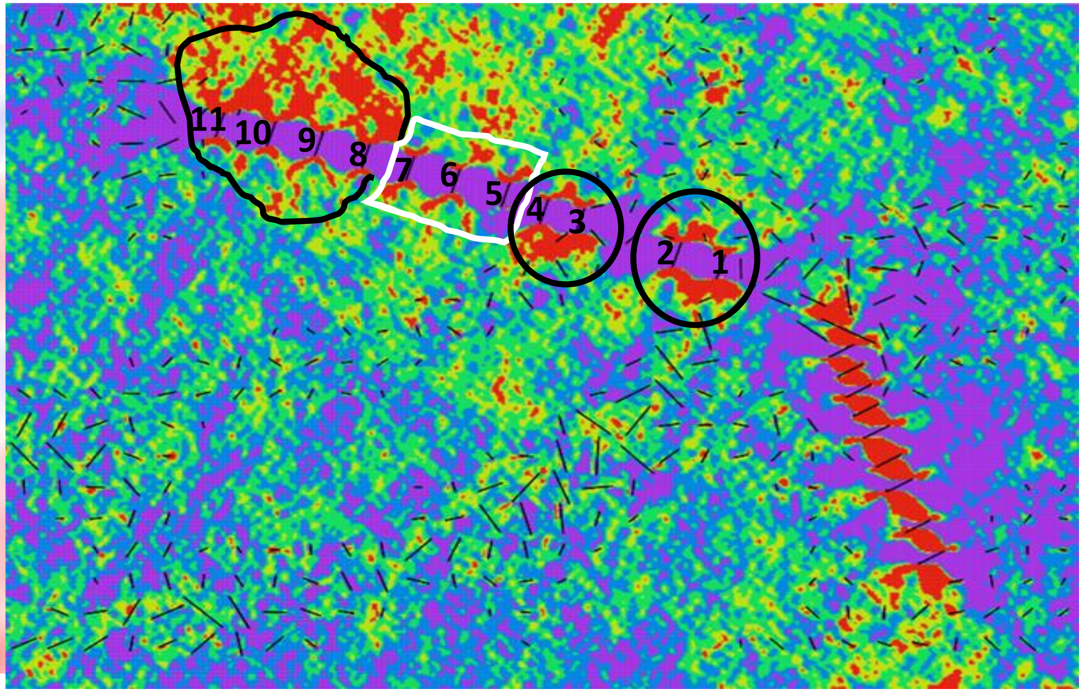
Geomechanical predictions vs tracers

URTeC 1923762



A: Predictions from Meek et al. (2013)



B: Microseismic predictions from MPM geomechanical simulations

- Well-developed toe area (8 to 11), fracing could be relatively successful
- Poor performance of the middle part of the well as confirmed by the tracers
- The heel stages 1 & 2 and next 3&4 show an average fracing.

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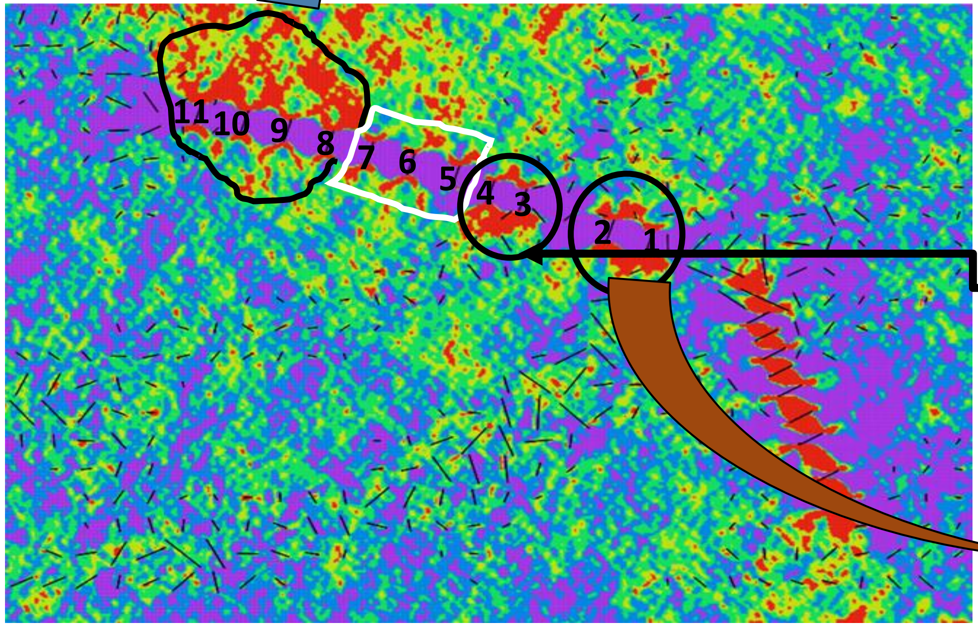
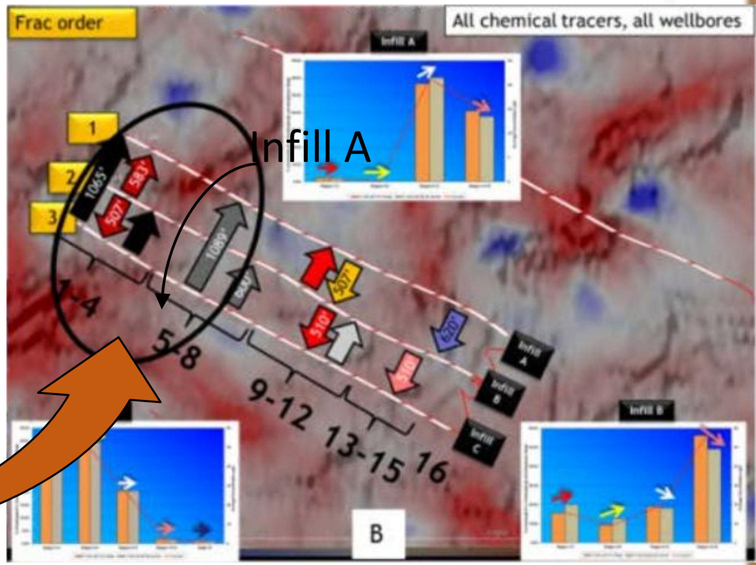
Infill A MS predictions vs tracers



B: Microseismic predictions from MPM geomechanical simulations



B: Tracers from Portis et al. (2013)

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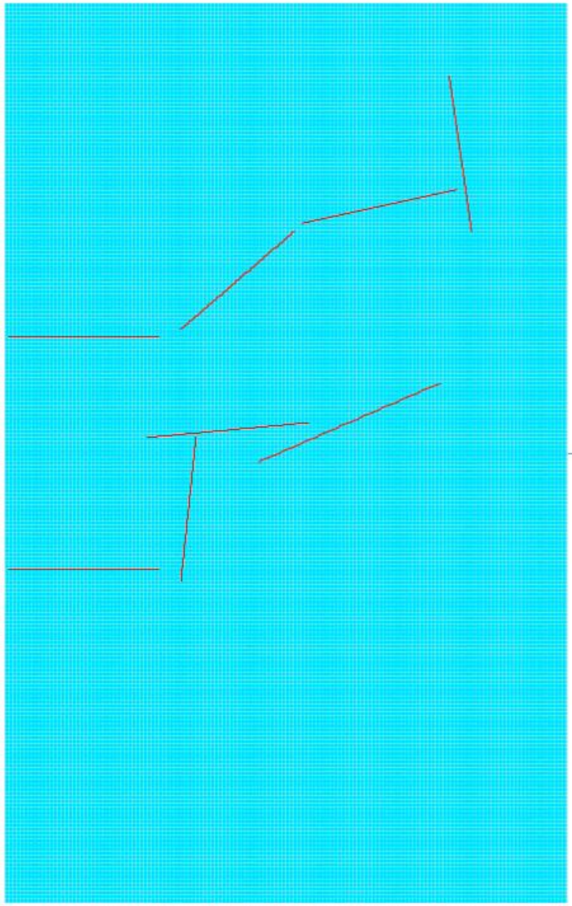
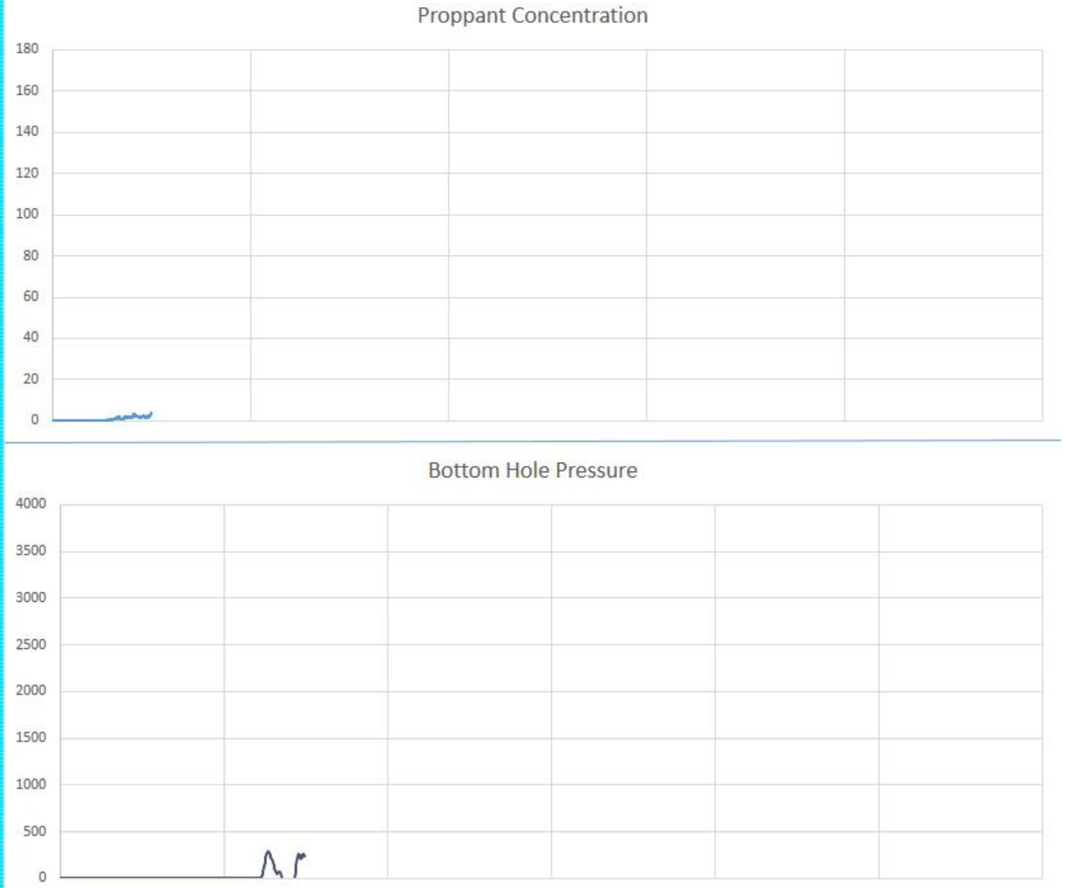
Effect of multiple fractures on proppant distribution





Thank you !

- Using Geomechanical Modeling to Quantify the Impact of Natural Fractures on Well Performance and Microseismicity: Application to the Wolfcamp, Permian Basin, **URTeC 2173459, 2015**
- Predicting frac stage differential stress and microseismicity using geomechanical modeling and time lapse multi-component seismic- Application to the Montney shale, **SPE 174054, 2015**
- Interpretation of Microseismic Using Geomechanical Modeling of Multiple Hydraulic Fractures Interacting with Natural Fractures – Application to Montney Shale, **CSEG Recorder, November 2014**.
- Predicting Microseismicity from Geomechanical Modeling of Multiple Hydraulic Fractures Interacting with Natural Fractures – Application to the Marcellus and Eagle Ford, **URTeC 1923762, 2014**
- Modeling Multiple Hydraulic Fractures Interacting with Natural Fractures Using the Material Point Method, **SPE 167801, 2014**

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