Using Geomechanical Modeling to Quantify the Impact of Faults on Multiple Phases of Unconventional Resource Production*

Nicholas Umholtz[1]

Search and Discovery Article #80522 (2016)**
Posted March 14, 2016

*Adapted from oral presentation given at AAPG-SPE Joint Forum, Reality-Based Reservoir Development: New Teams, Techniques, Technologies, Oklahoma City, Oklahoma, September 23, 2015

[1]FracGeo, The Woodlands, TX (numholtz@fracgeo.com)

Abstract

This study describes workflows to quantify the impact of natural fractures on the performance of shale wells. First, a method described by White et al., (2014) is reviewed to illustrate the regression analysis approach which may be used on a small area where many image logs and production are available. Then, a general workflow that combines Geophysics, Geology, and Geomechanics (3G) is discussed and applied to a Wolfcamp well. The benefits of the 3G workflow are threefold. First, the quantitative impact of the natural fractures on the regional stress is provided through the differential horizontal stress variation which impacts frac complexity. Secondly, an effective modeling technique which accounts for the interaction between the hydraulic and natural fractures in creating the reservoir strain and drainage pathways is described and validated using microseismic data. Thirdly, the ability of this model to identify the poor hydraulic fracturing stages due to the excessive or low fracture density encountered along the wellbore is discussed.

The impact of natural fractures on the efficiency of a hydraulic fracture is quantified using geomechanical modeling that is able to identify poor hydraulic fracturing stages clustered where there are too many natural fractures near faults or around low fracture density zones. The best hydraulic fracturing stages appear to cluster where there are sufficient natural fractures to create complexity, and are often proximal to large natural fracture trends associated with faults.

Building on the validated 3G workflow, a well placement workflow that takes into the account the quantitative impact of natural fractures on the well performance is demonstrated on the considered Wolfcamp B well. The workflow provides the optimal position of a well in the presence of natural fractures associated with a fault system that could produce undesirable water.

Selected References

Aimene, Y.E., and J.A. Nairn, 2014, Modeling Multiple Hydraulic Fractures Interacting with Natural Fractures Using the Material Point Method: SPE/EAGE European Unconventional Resources Conference and Exhibition, 25-27 February, Vienna, Austria, SPE-167801-MS, 20 p. doi:10.2118/167801-MS

Grossi, P., 2015, Investigating Natural Fracture Effects on Well Productivity: Eagle Ford, La Salle County, Unconventional Resources Technology Conference, 20-22 July, San Antonio, Texas, SPE-178508-MS, 15 p. doi:10.2118/178508-MS

Houston, M., 2013, Microseismic, 3D, and Log Image Data for Unconventional Targeted Drilling and Treatment: Pacific Section AAPG, SEG and SEPM Joint Technical Conference, Monterey, California, April 19-25, 2013, Search and Discovery Article #41135 (2013). http://www.searchanddiscovery.com/documents/2013/41135houston/ndx_houston.pdf. Website accessed March 2016.

King, V.M., and L. Wray, 2014, Completion Optimization Utilizing Multivariate Analysis in the Bakken and Three Forks Formations: SPE Western North American and Rocky Mountain Joint Meeting, 17-18 April, Denver, Colorado, SPE-169534-MS, 12 p. doi:10.2118/169534-MS

Nairn, J.A., 2003, Material Point Method Calculations with Explicit Cracks: Computer Modeling in Engineering and Science, v.4/6, p.649-663.

Ouenes, A., 2014, Distribution of Well Performances in Shale Reservoirs and Their Predictions Using the Concept of Shale Capacity: SPE/EAGE European Unconventional Resources Conference and Exhibition, 25-27 February, Vienna, Austria, SPE-167779-MS, 15 p. doi:10.2118/167779-MS

Ouenes, A., 2013, ‘Shale Capacity’ Key in Shale Modeling: The American Oil and Gas Reporter, v. 7, 6 p.

Ouenes, A., 2012, Seismically Driven Characterization of Unconventional Shale Plays: Canadian Society of Exploration Geophysics, v. 37/2, p. 22-28.

Ouenes, A., N. Umholtz, and Y. Aimene, 2015, Using Geomechanical Modeling to Quantify the Impact of Natural Fractures on Well Performance and Microseismicity: Application to the Wolfcamp, Permian Basin: paper URTeC 2173459 presented at the 2015 Unconventional Resources Technology Conference, July 20-22, San Antonio.

Sulsky, D., Z. Chen, and H.L. Schreyer, 1994, A Particle Method for History-Dependent Materials: Computer Methods in Applied Mechanics and Engineering, v. 118, p. 179-196.

Umholtz, N., and A. Ouenes, 2015, Optimal Fracing Near Faults - Quantifying the Interaction Between Natural and Hydraulic Fractures Using Geomechanical Modeling: SPE Asia Pacific Unconventional Resources Conference and Exhibition, 9-11 November, Brisbane, Australia, SPE-176932-MS. 15 p. doi:10.2118/176932-MS

USGS, 2015, Oklahoma Area Seismicity, 1970-2015. http://earthquake.usgs.gov/earthquakes/states/oklahoma/images/OKseismicity.pdf. Website accessed March 2016.

White, T., P. Clarke, A. Stephens, H. Ye, and M. Laughland, 2014, Fault and Fracture Characterization from an Integrated Subsurface and Seismic Dataset: Impact on Well Performance of the Wolfcamp Shale, Midland Basin, West Texas: paper URTeC 1934166 presented at 2014 Unconventional Resources Technology Conference, August 25-27, Denver. doi:10.15530/urtec-2014-1934166

Using Geomechanical Modeling to Quantify the Impact of Faults on Multiple Phases of Unconventional Resource Production

Nick Umholtz

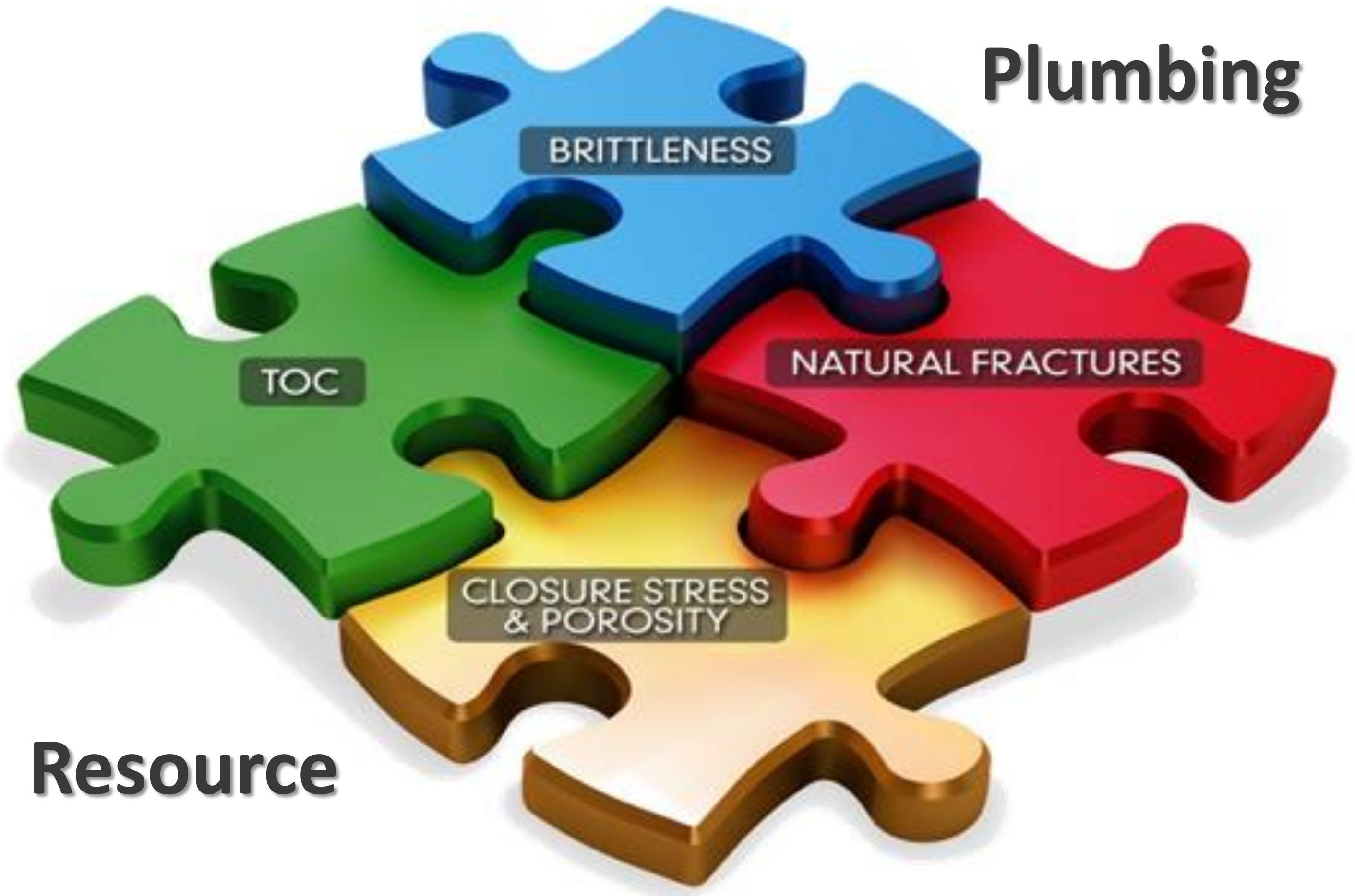
numholtz@fracgeo.com

09/23/15

Outline

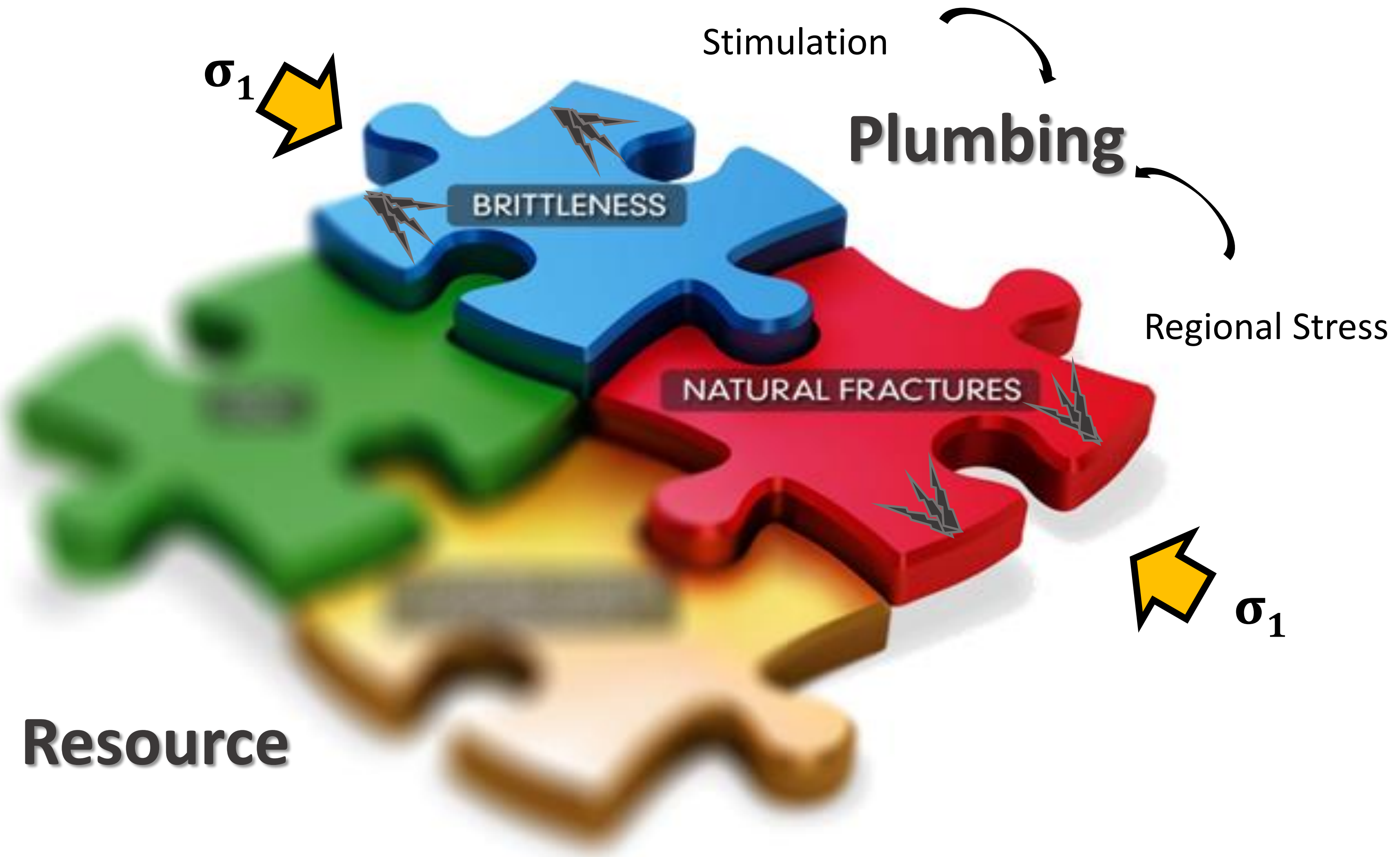
- Background
- Elementary Models
- Case Studies
  - Wolfcamp – Geohazard mitigation
  - Eagle Ford – Stress rotations
  - Oklahoma – Induced seismicity

Geologic Sweet Spots



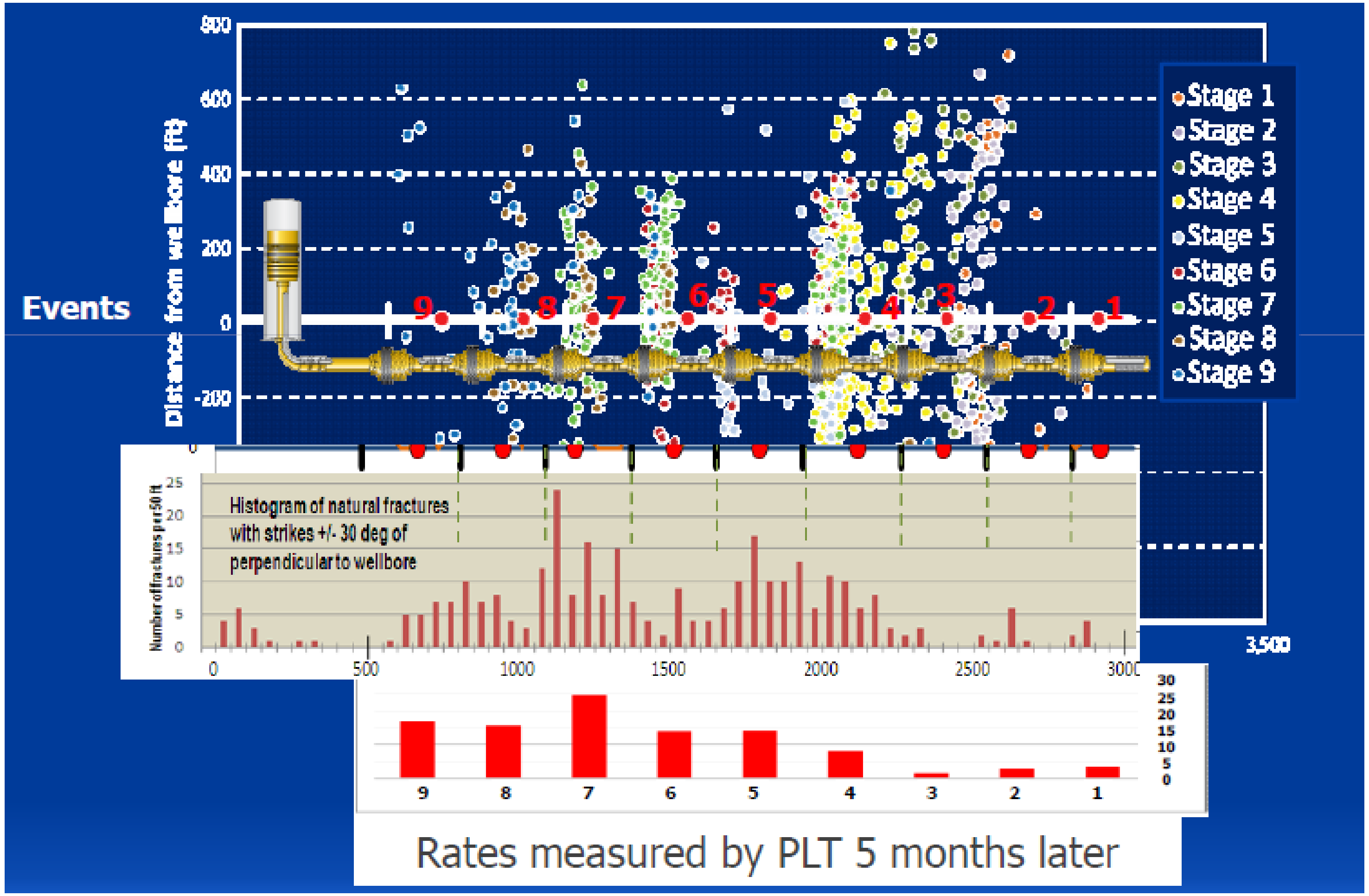
Ouenes, CSEG Recorder, 2012
Ouenes, AOGR, 2013
SPE 167779

Geomechanical Sweet Spots



SPE 167779

Relationship between fractures and production

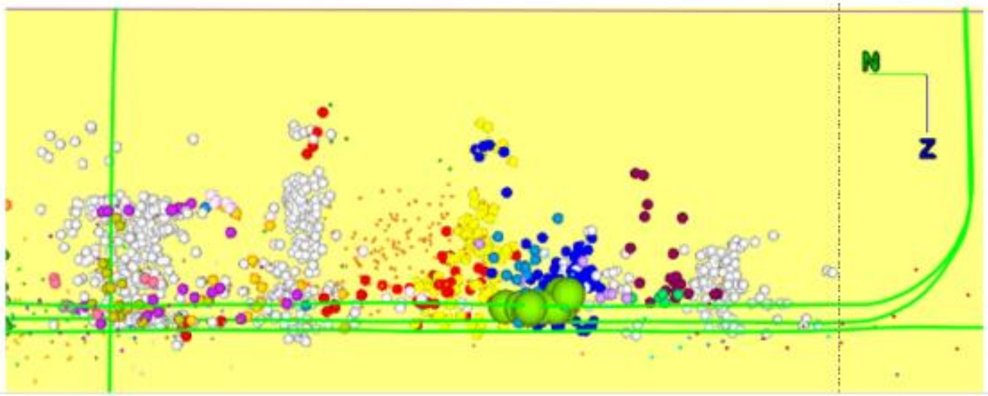


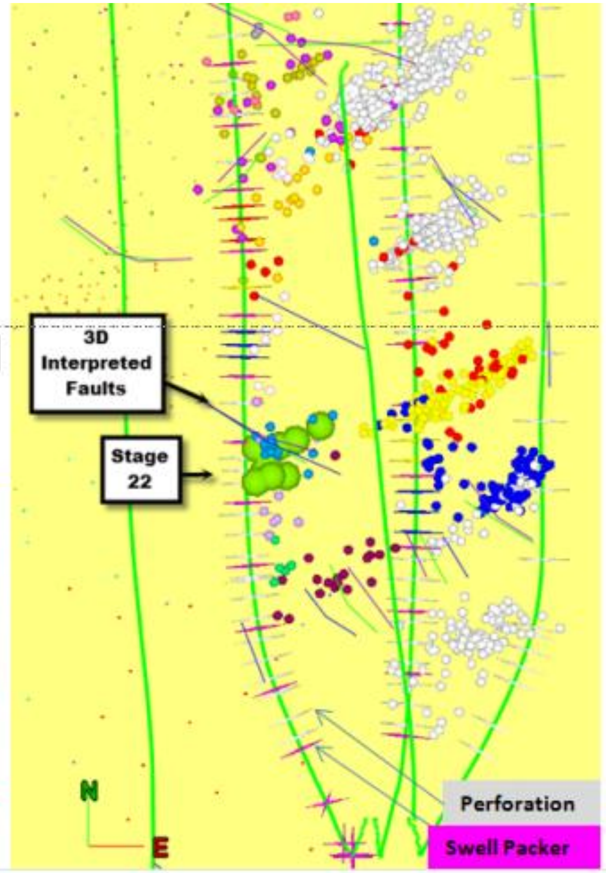
Rates measured by PLT 5 months later

Search & Discovery #41135

Relationship between fractures and production

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





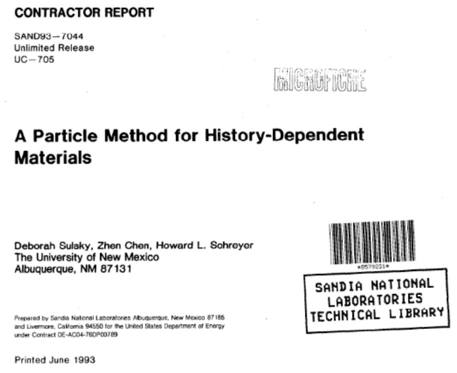
SPE 169534

Geomechanical Modeling

- The use of geomechanics is necessary to quantify the interaction between hydraulic and natural fractures
- A new geomechanical technology (Aimene & Nairn 2014), 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
- At each time step, particles' information are extrapolated to the background grid to solve the equations of motion
- CRAMP is MPM extended to handle explicit fractures (Nairn, 2003)


CONTRACTOR REPORT

SAND93—7044
Unlimited Release
UC—705

MICROFICHE

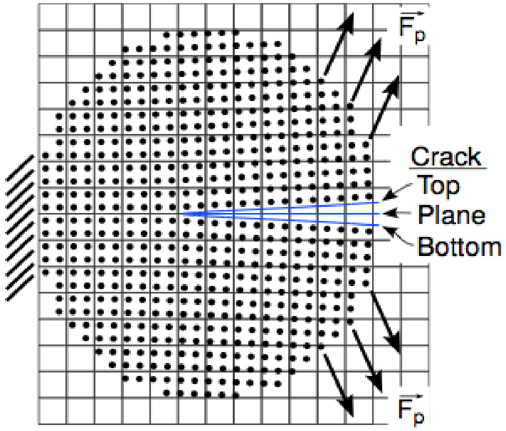
A Particle Method for History-Dependent Materials

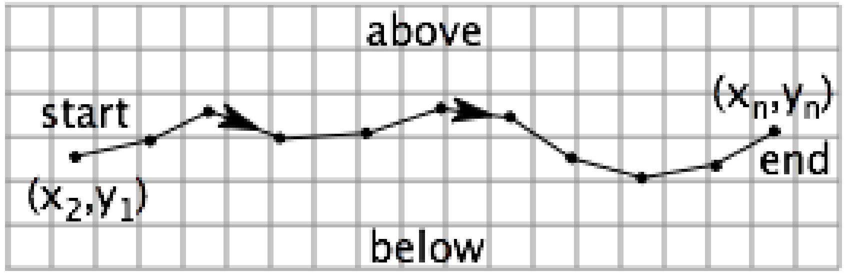
Deborah Sulsky, Zhen Chen, Howard L. Schreyer
The University of New Mexico
Albuquerque, NM 87131

SANDIA NATIONAL LABORATORIES TECHNICAL LIBRARY

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

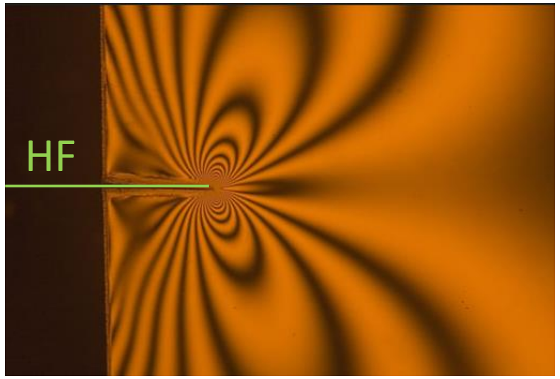


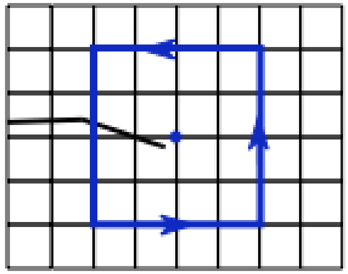


Fracture Mechanics

- 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

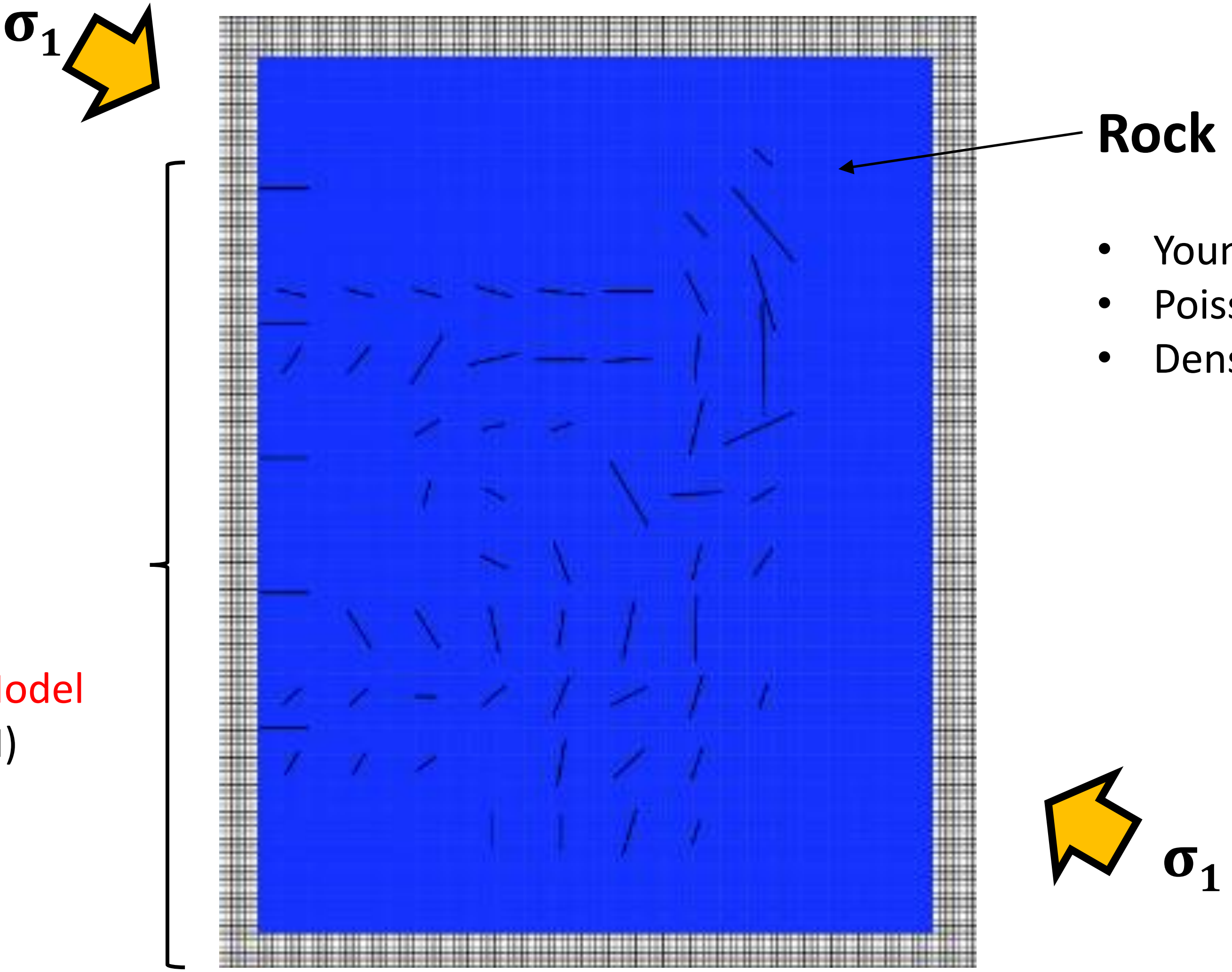
Stress field around crack tip





G = J Integral

Inputs to the model



Rock Mechanical Properties

- Young's Modulus
- Poissons Ratio
- Density

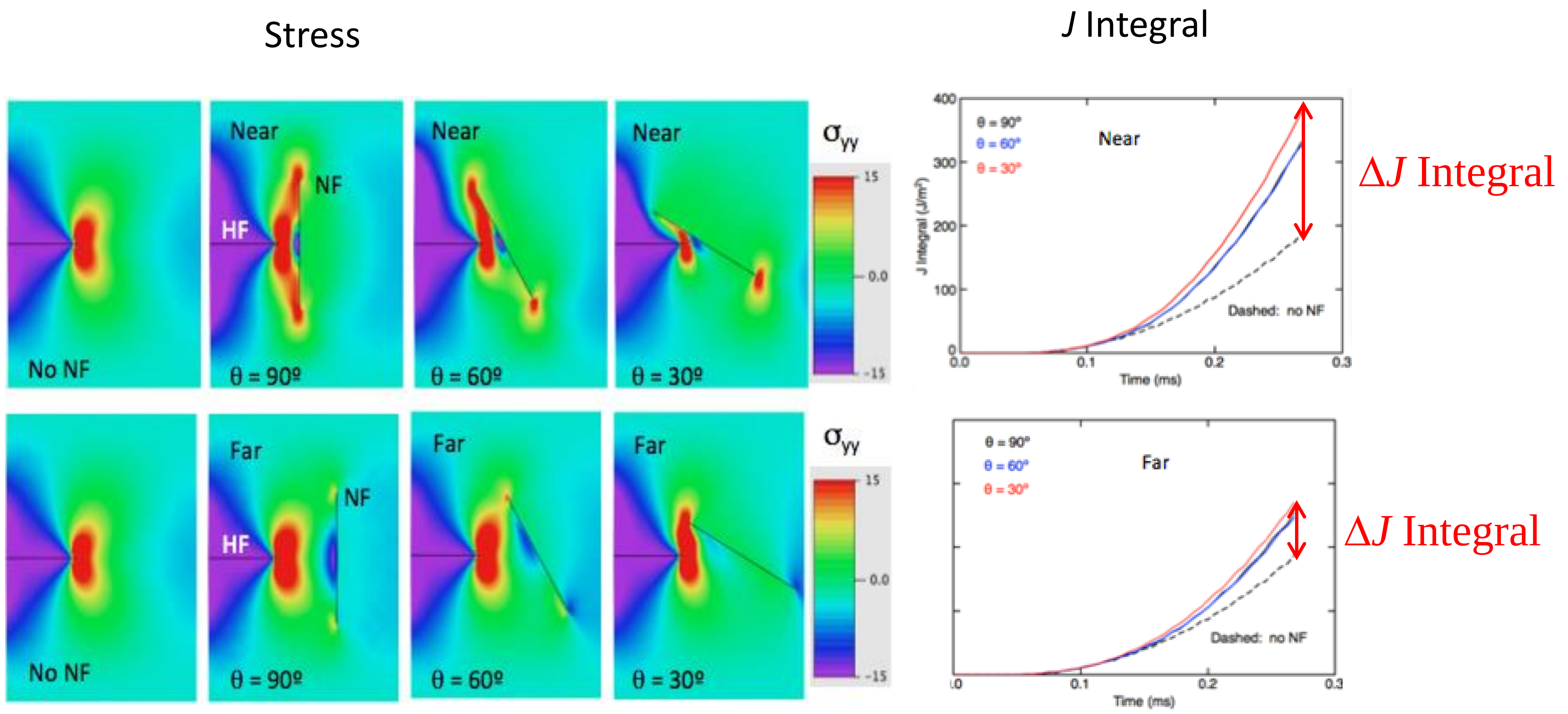
Fractures

- Fracture Model (from CFM)
- Hydraulic

Regional Stress

- Orientation
- Magnitude
- Anisotropy

Effect of Natural Fractures on *J* Integral

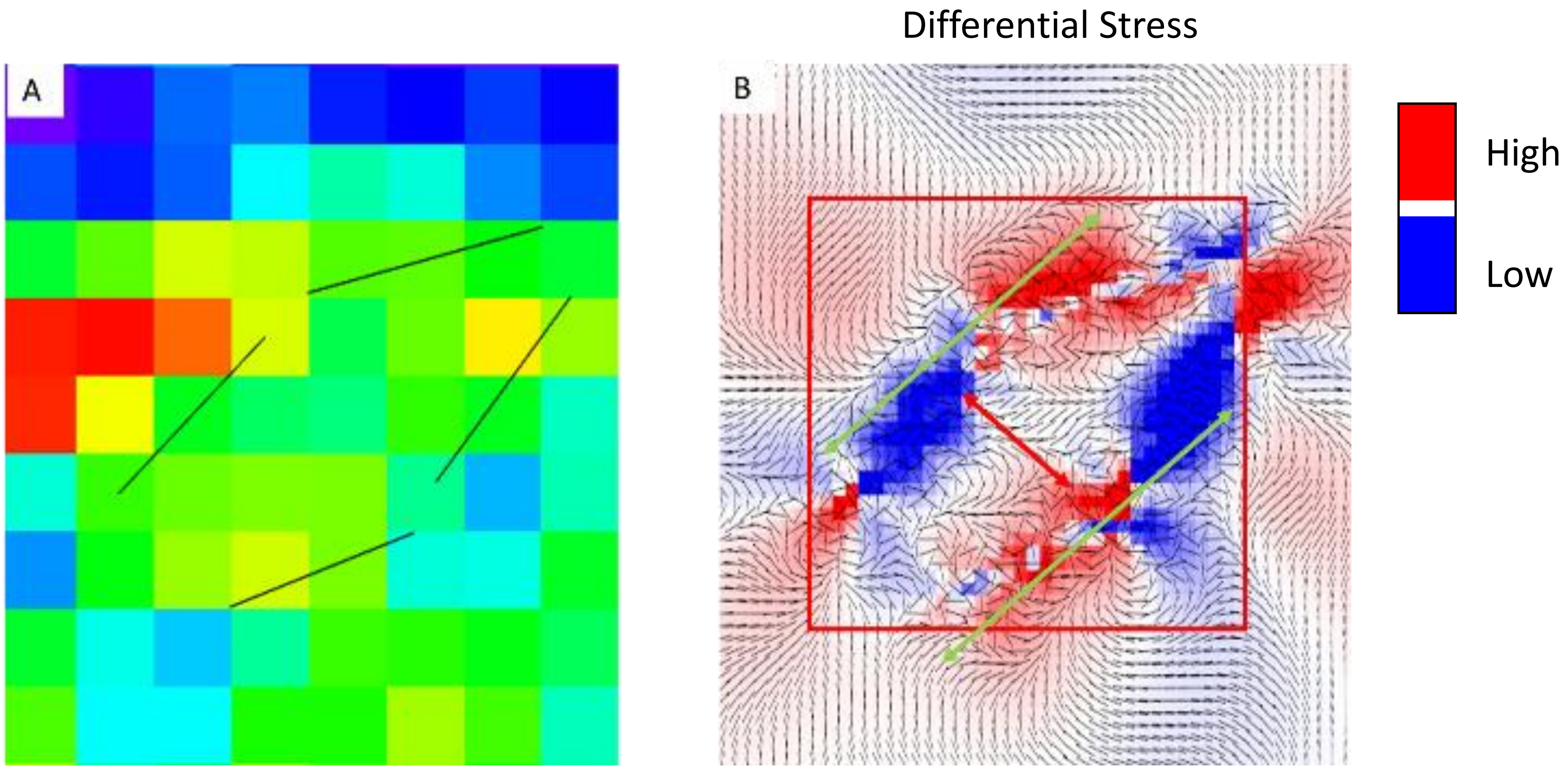


$\Delta J = J_F - J_{noF}$

A higher stress field when the NF is near the HF
as a consequence of NF opening in a nearby rather than in far position

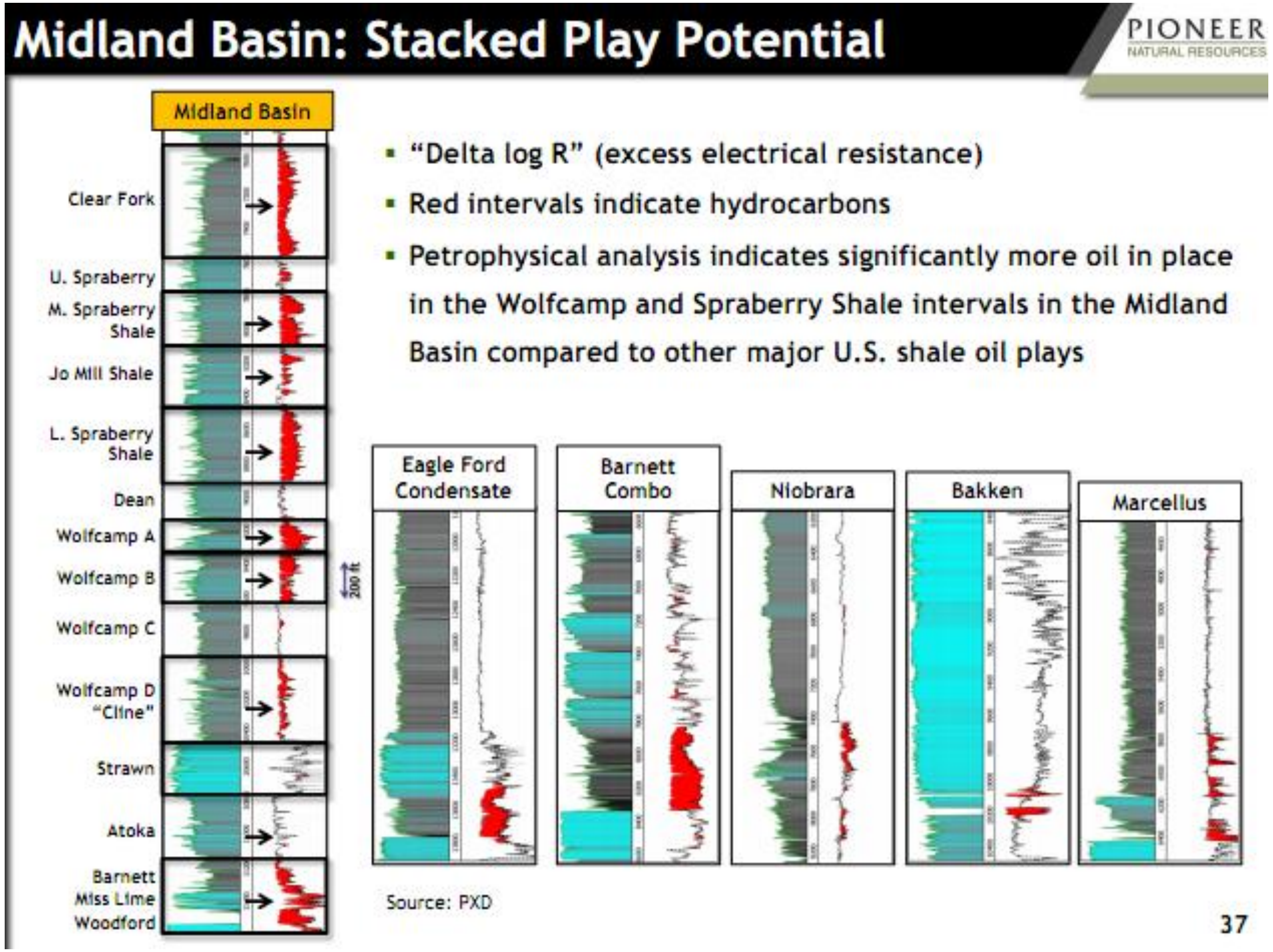
URTeC 2173459

Elementary fault block stress rotation model

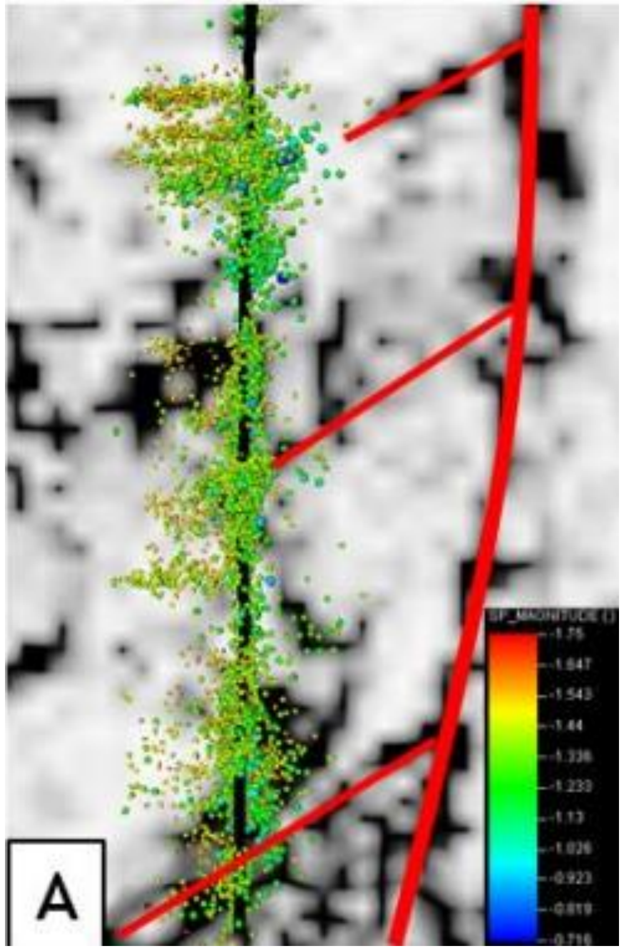


SPE 176932

A Wolfcamp Study



PXD investor presentation, 2014



URTeC 1934166

PXD relating natural fractures to production using regression analysis

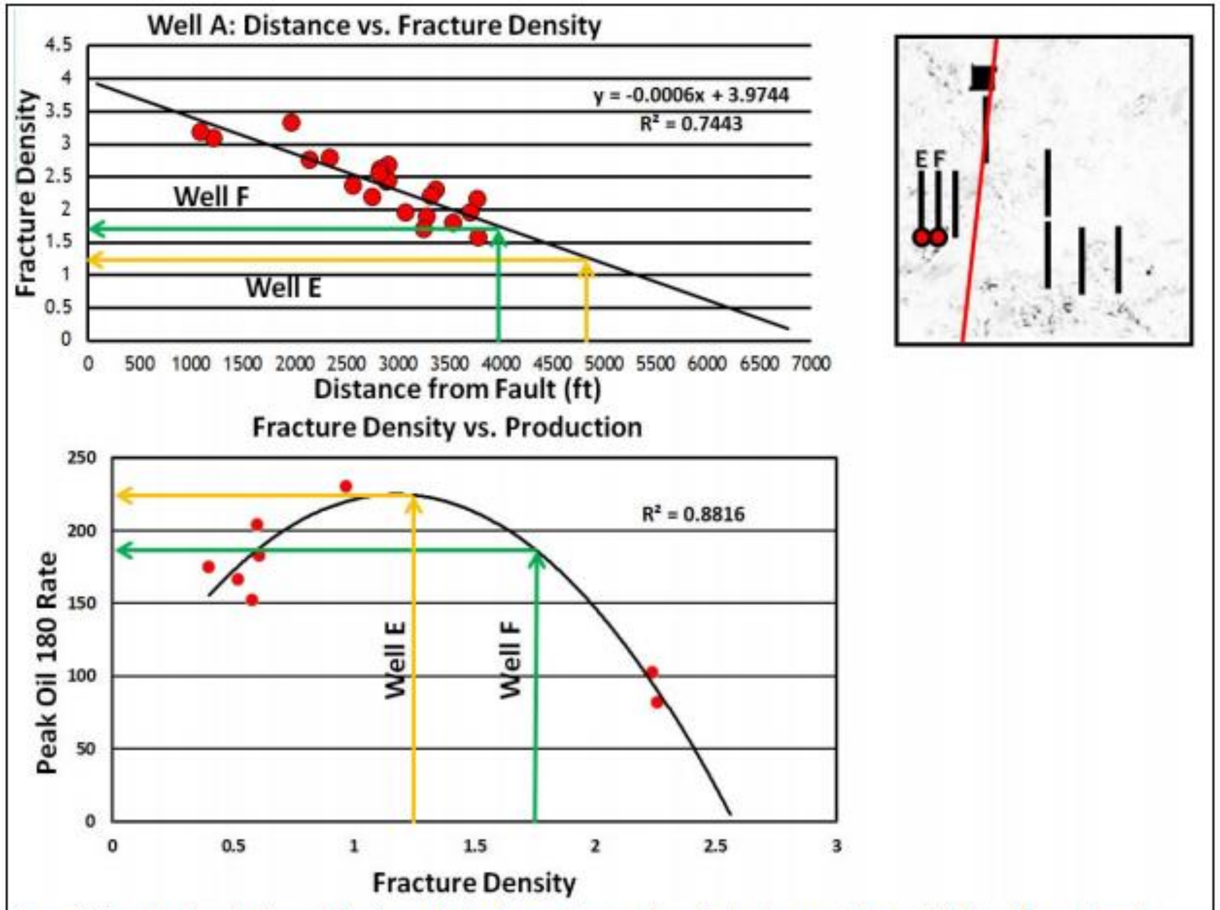


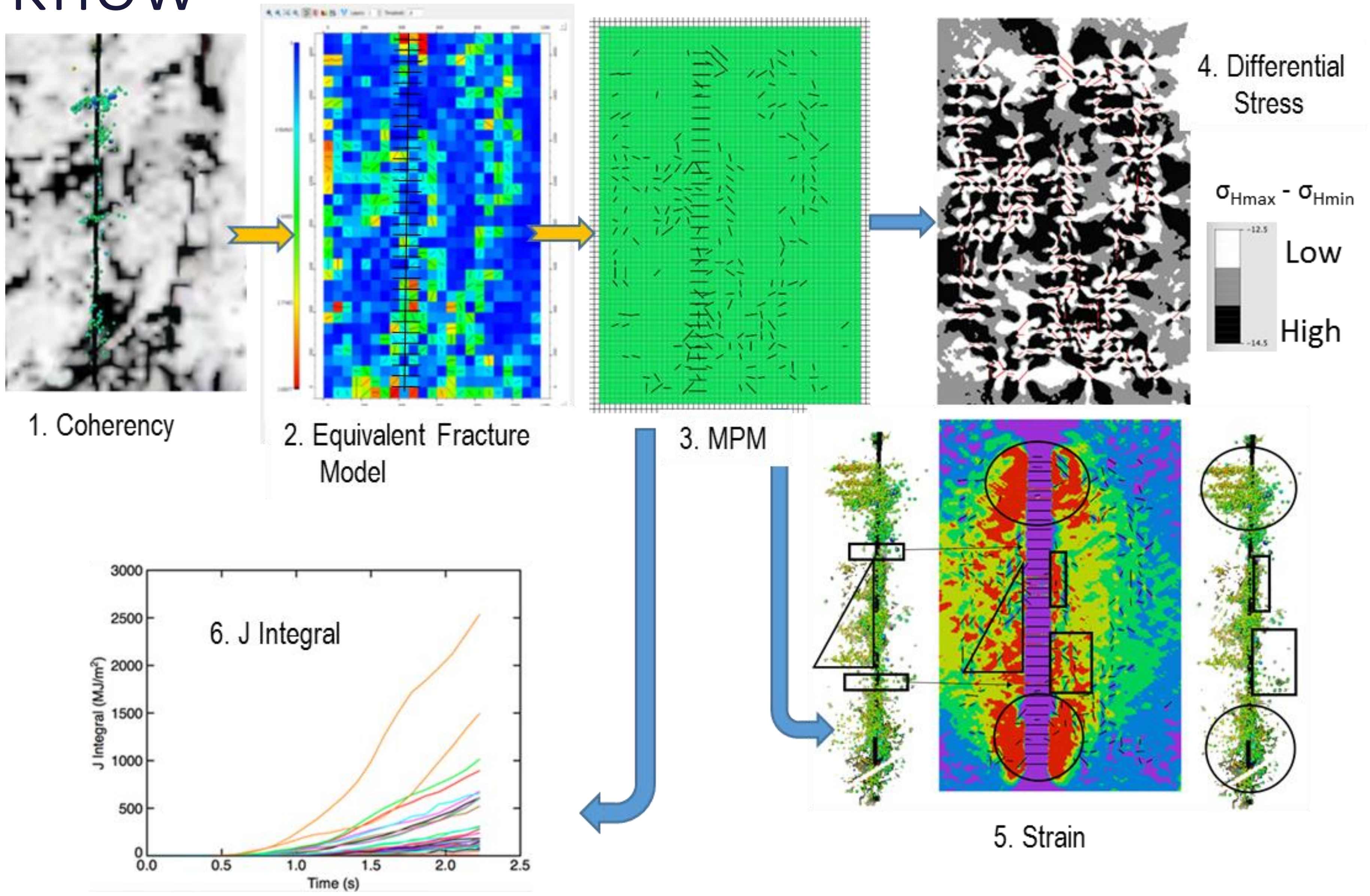
Figure 7- Two plots describe the workflow for predicting fracture density and correlating that to production. Wells E and F are assigned a predicted fracture density based on their average distance from the fault (top left). Using that fracture density the wells' production is estimated using the regression (bottom left).

URTeC 1934166

The Pioneer work is extended to examine the details of what happens at each frac stage and identify the poor frac stages

Geomechanical modeling will be used to study the interaction between the hydraulic fractures and the natural fractures

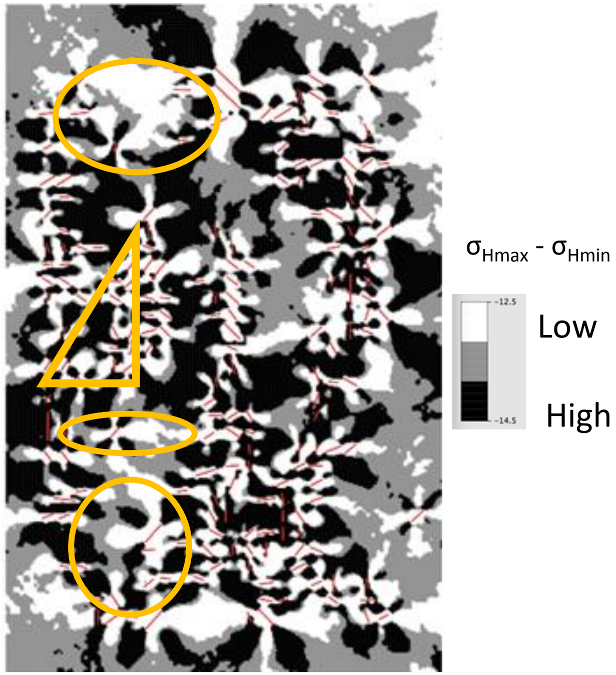
3G Workflow



1. Coherency
2. Equivalent Fracture Model
3. MPM
4. Differential Stress
$\sigma_{Hmax} - \sigma_{Hmin}$
Low
High
5. Strain
6. J Integral
J Integral (MJ/m²)
Time (s)

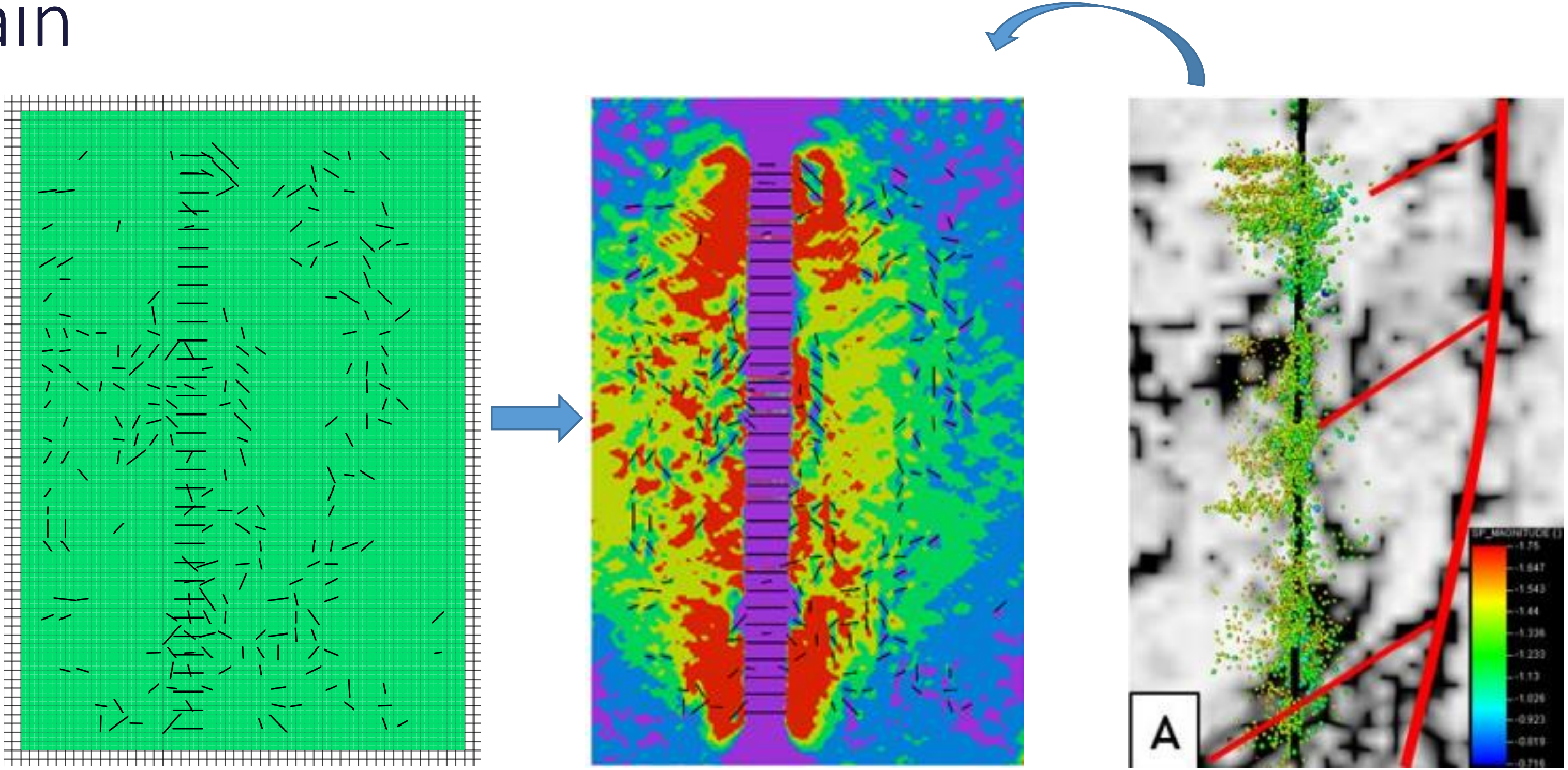
Validating the Differential Stress with MS

A. Interpreted microseismicity



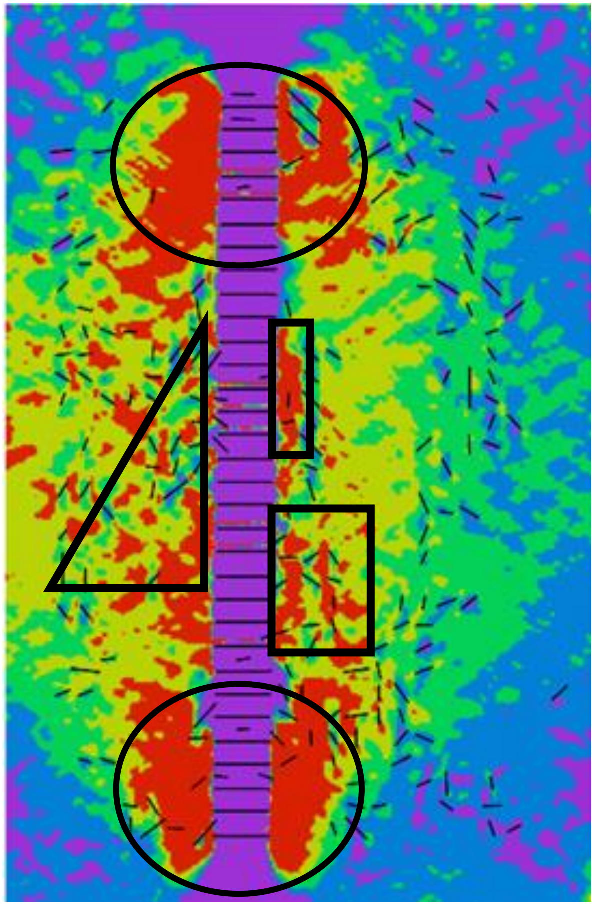
B. Simulated Differential Stress

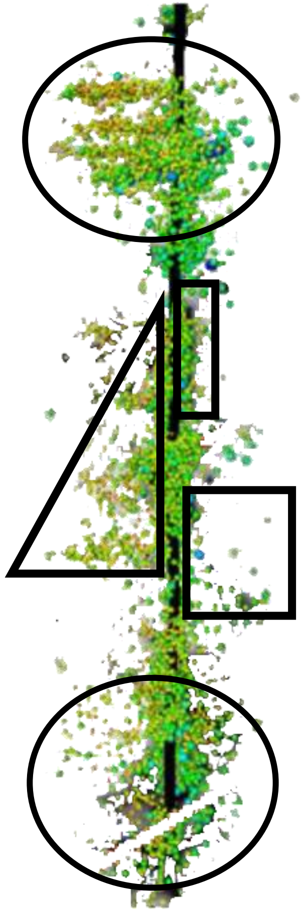
Putting pressure in the HF and predicting the strain



URTeC 2173459

Validating Strain with MS



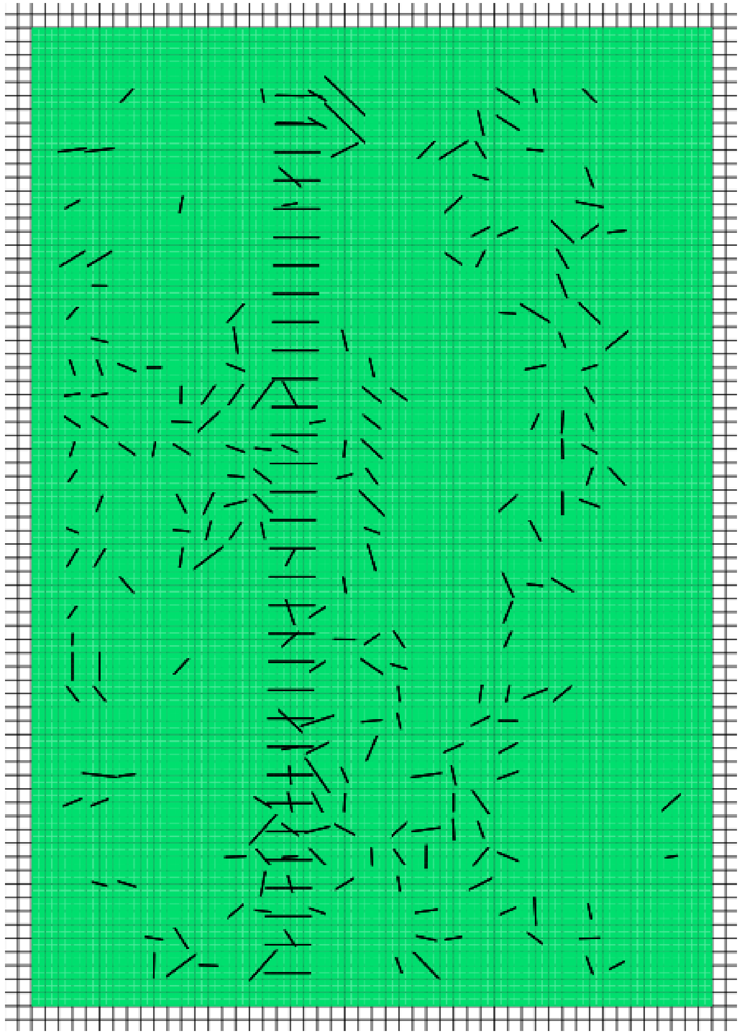


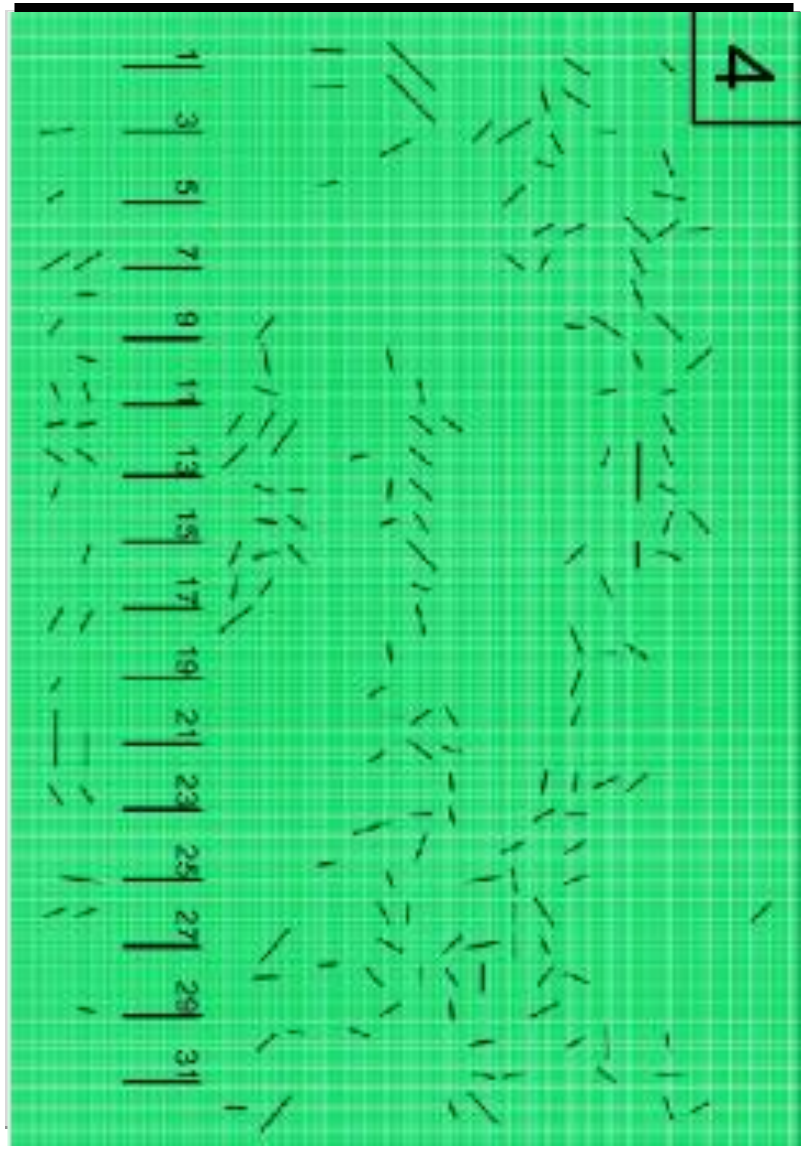
Asymmetric, Discontinued “Poor” stimulation

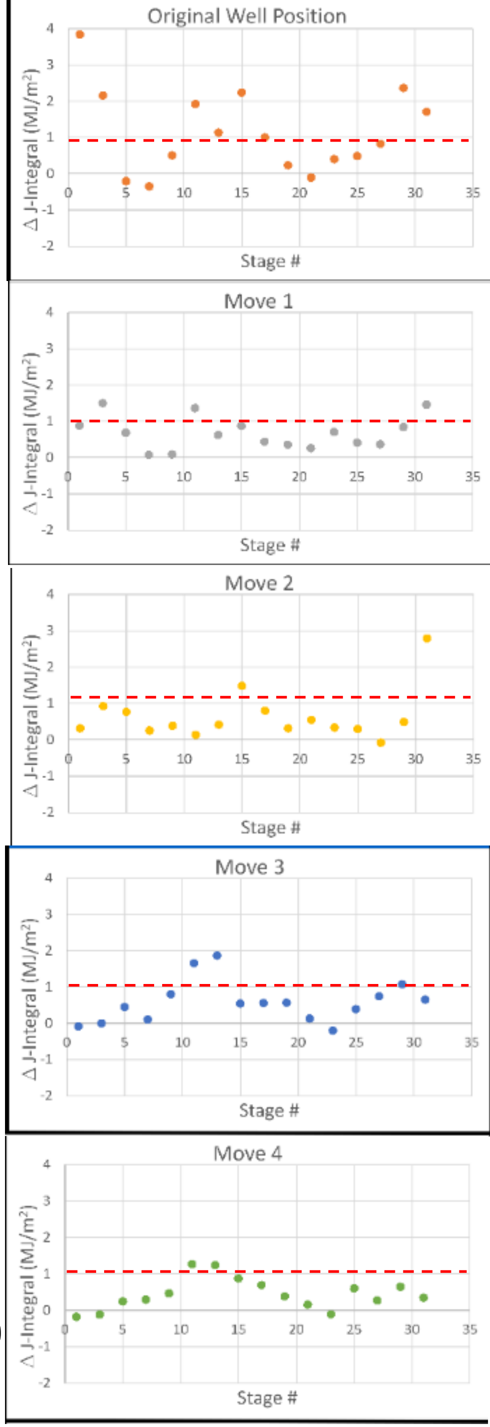
Large SRV successful stimulation

URTeC 2173459

Completion Optimization using ΔJ Integral

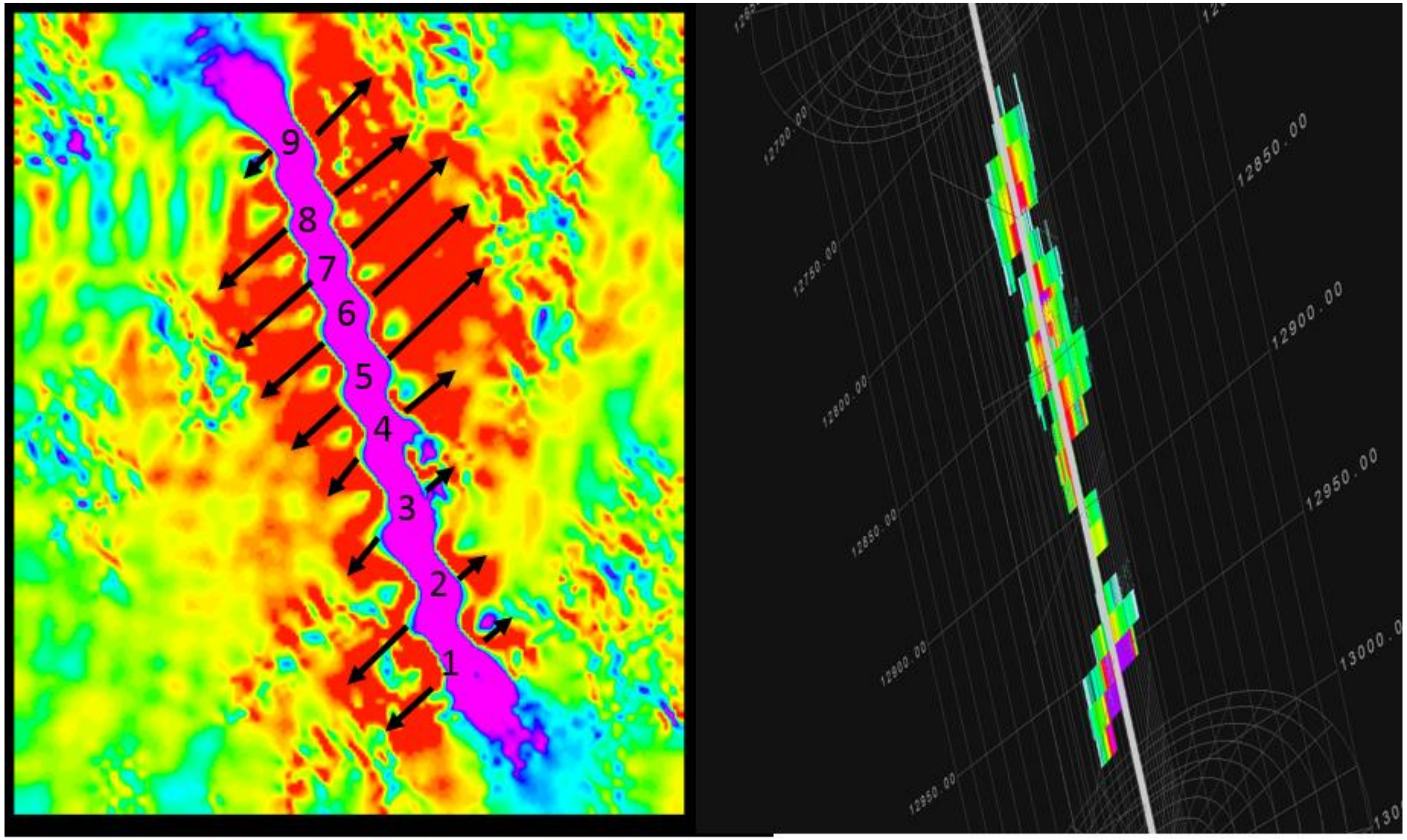






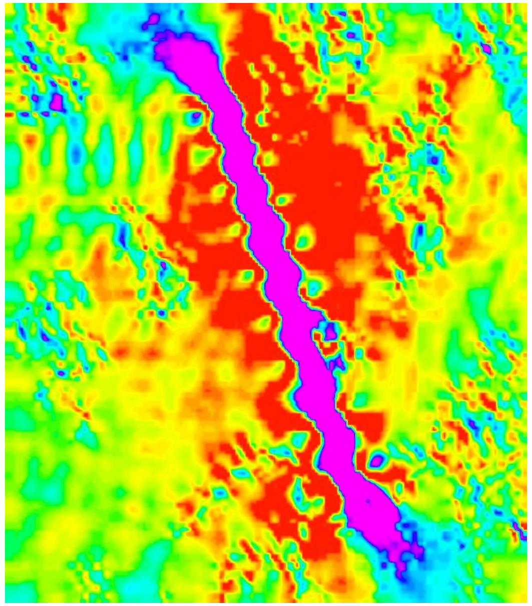
URTeC 2173459

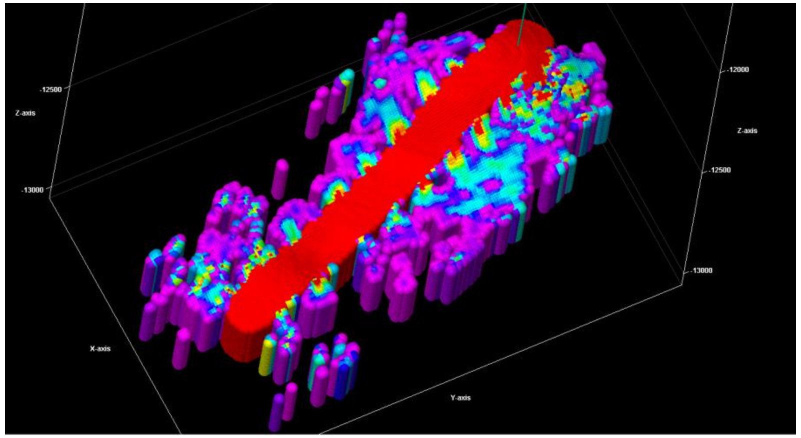
Strain Map vs. Propped Volume Through Frac Design

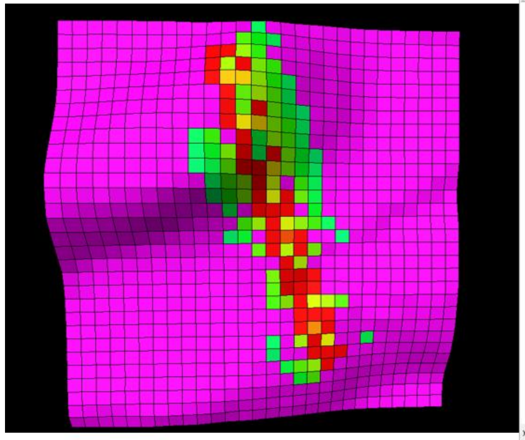


A: Strain map B: Propped volume

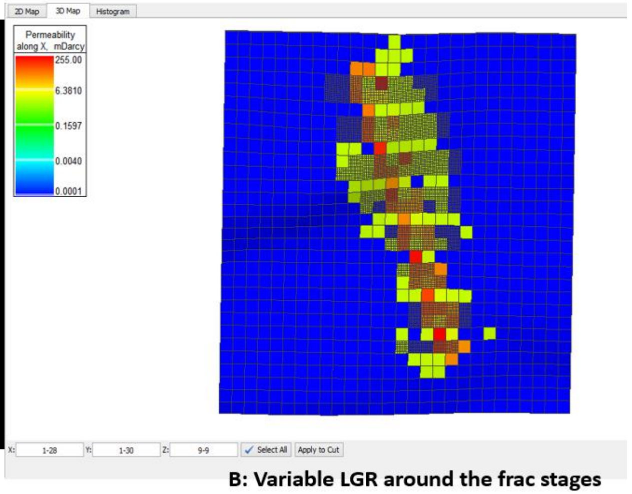
Reservoir Simulation Workflow



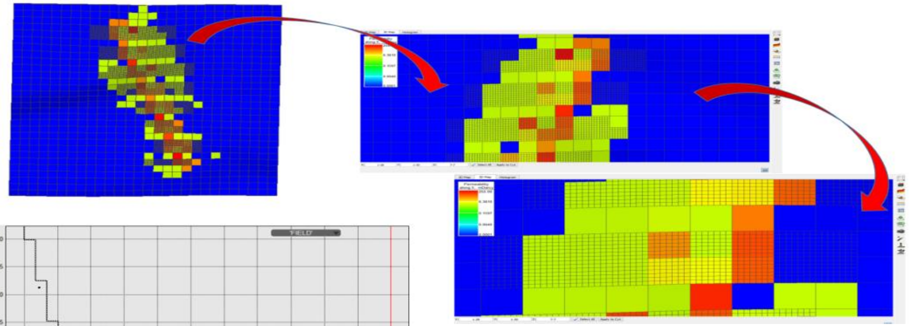


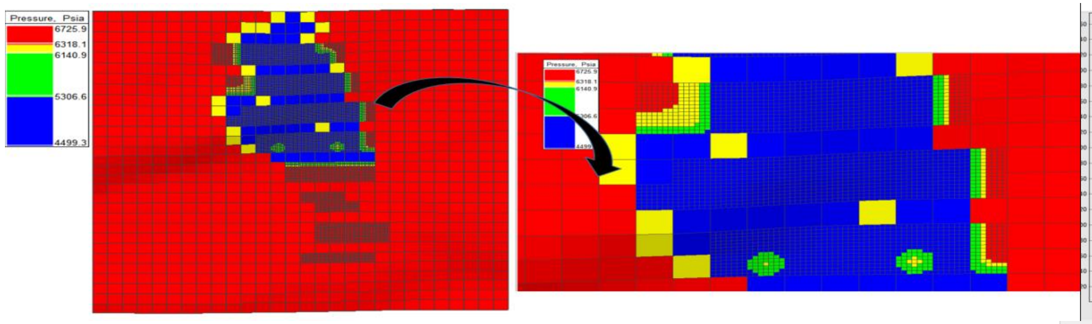


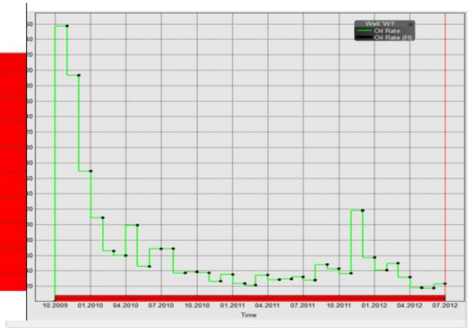
A: Stimulated Permeability Model



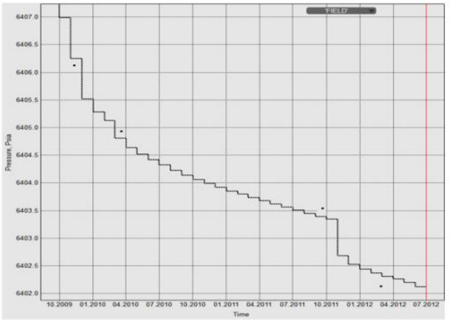
B: Variable LGR around the frac stages





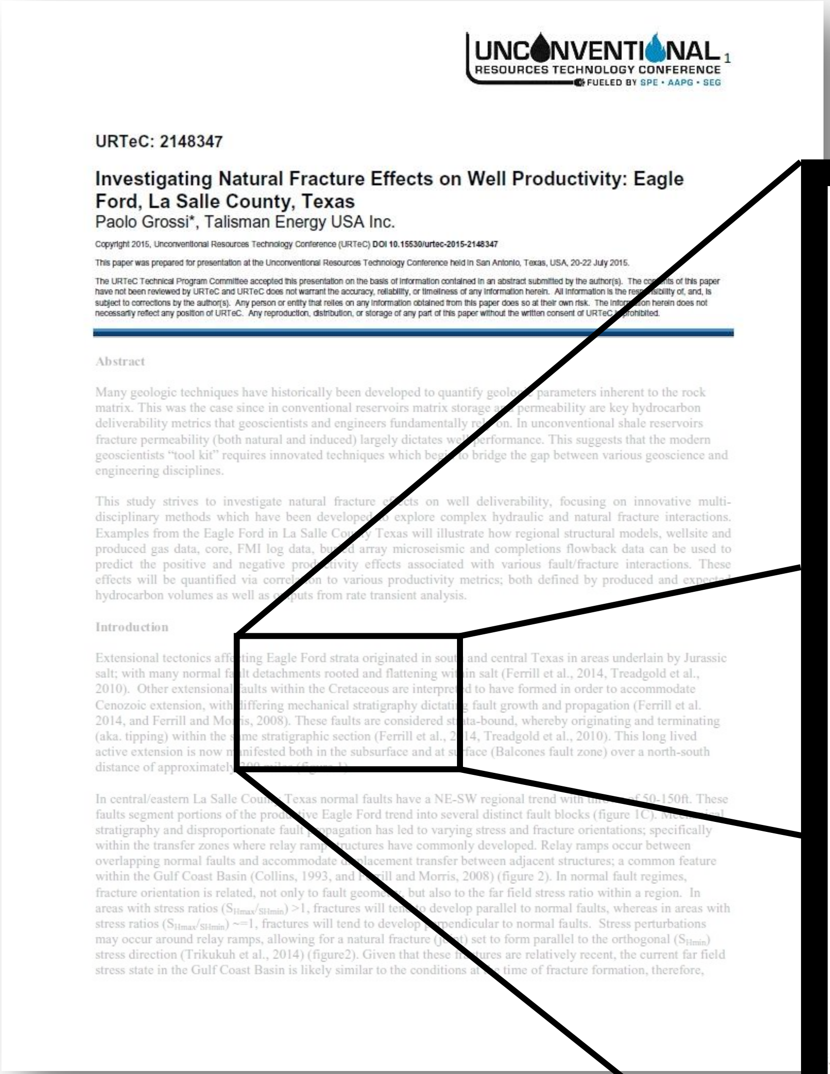


A: Matching the oil rate



B: Matching the bottom hole pressure

Application to Eagle Ford Data


UNCONVENTIONAL RESOURCES TECHNOLOGY CONFERENCE · FUELED BY SPE · AAPG · SEG 1

URTeC: 2148347

Investigating Natural Fracture Effects on Well Productivity: Eagle Ford, La Salle County, Texas

Paolo Grossi*, Talisman Energy USA Inc.

This paper was prepared for presentation at the Unconventional Resources Technology Conference held in San Antonio, Texas, USA, 20-22 July 2015.

Abstract

Many geologic techniques have historically been developed to quantify geologic parameters inherent to the rock matrix. This was the case since in conventional reservoirs matrix storage and permeability are key hydrocarbon deliverability metrics that geoscientists and engineers fundamentally rely on. In unconventional shale reservoirs fracture permeability (both natural and induced) largely dictates well performance. This suggests that the modern geoscientists "tool kit" requires innovated techniques which begin to bridge the gap between various geoscience and engineering disciplines.

This study strives to investigate natural fracture effects on well deliverability, focusing on innovative multi-disciplinary methods which have been developed to explore complex hydraulic and natural fracture interactions. Examples from the Eagle Ford in La Salle County Texas will illustrate how regional structural models, wellsite and produced gas data, core, FMI log data, buried array microseismic and completions flowback data can be used to predict the positive and negative productivity effects associated with various fault/fracture interactions. These effects will be quantified via correlation to various productivity metrics; both defined by produced and expected hydrocarbon volumes as well as outputs from rate transient analysis.

Introduction

Extensional tectonics affecting Eagle Ford strata originated in south and central Texas in areas underlain by Jurassic salt; with many normal fault detachments rooted and flattening within salt (Ferrill et al., 2014, Treadgold et al., 2010). Other extensional faults within the Cretaceous are interpreted to have formed in order to accommodate Cenozoic extension, with differing mechanical stratigraphy dictating fault growth and propagation (Ferrill et al. 2014, and Ferrill and Morris, 2008). These faults are considered strata-bound, whereby originating and terminating (aka. tipping) within the same stratigraphic section (Ferrill et al., 2014, Treadgold et al., 2010). This long lived active extension is now manifested both in the subsurface and at surface (Balcones fault zone) over a north-south distance of approximately

In central/eastern La Salle County Texas normal faults have a NE-SW regional trend with throws of 50-150ft. These faults segment portions of the productive Eagle Ford trend into several distinct fault blocks (figure 1C). Mechanical stratigraphy and disproportionate fault propagation has led to varying stress and fracture orientations; specifically within the transfer zones where relay ramp structures have commonly developed. Relay ramps occur between overlapping normal faults and accommodate displacement transfer between adjacent structures; a common feature within the Gulf Coast Basin (Collins, 1993, and Ferrill and Morris, 2008) (figure 2). In normal fault regimes, fracture orientation is related, not only to fault geometry, but also to the far field stress ratio within a region. In areas with stress ratios (S_{Hmax}/S_{Hmin}) >1, fractures will tend to develop parallel to normal faults, whereas in areas with stress ratios (S_{Hmax}/S_{Hmin}) ~=1, fractures will tend to develop perpendicular to normal faults. Stress perturbations may occur around relay ramps, allowing for a natural fracture (joint) set to form parallel to the orthogonal (S_{Hmin}) stress direction (Trikukuh et al., 2014) (figure2). Given that these fractures are relatively recent, the current far field stress state in the Gulf Coast Basin is likely similar to the conditions at the time of fracture formation, therefore,

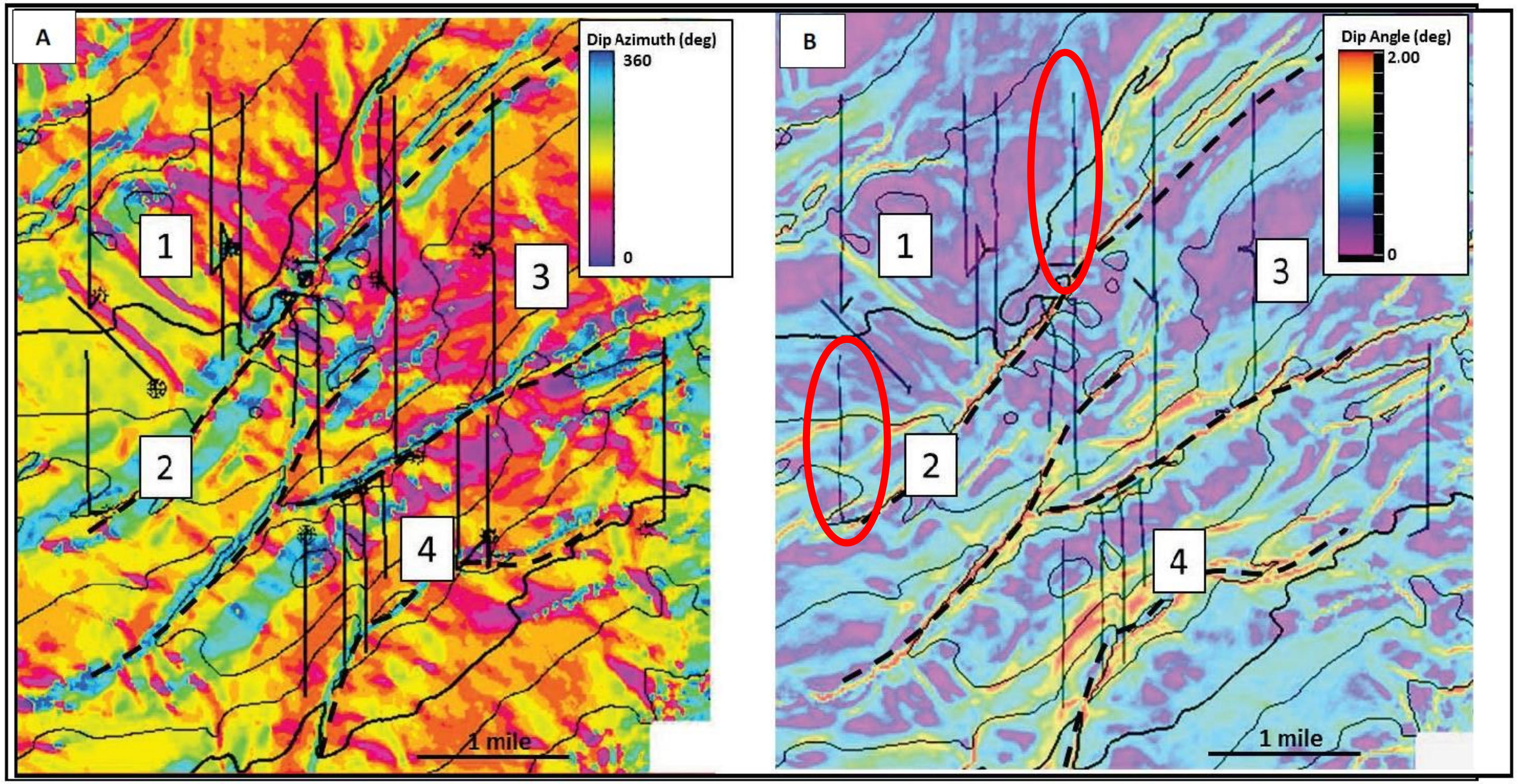
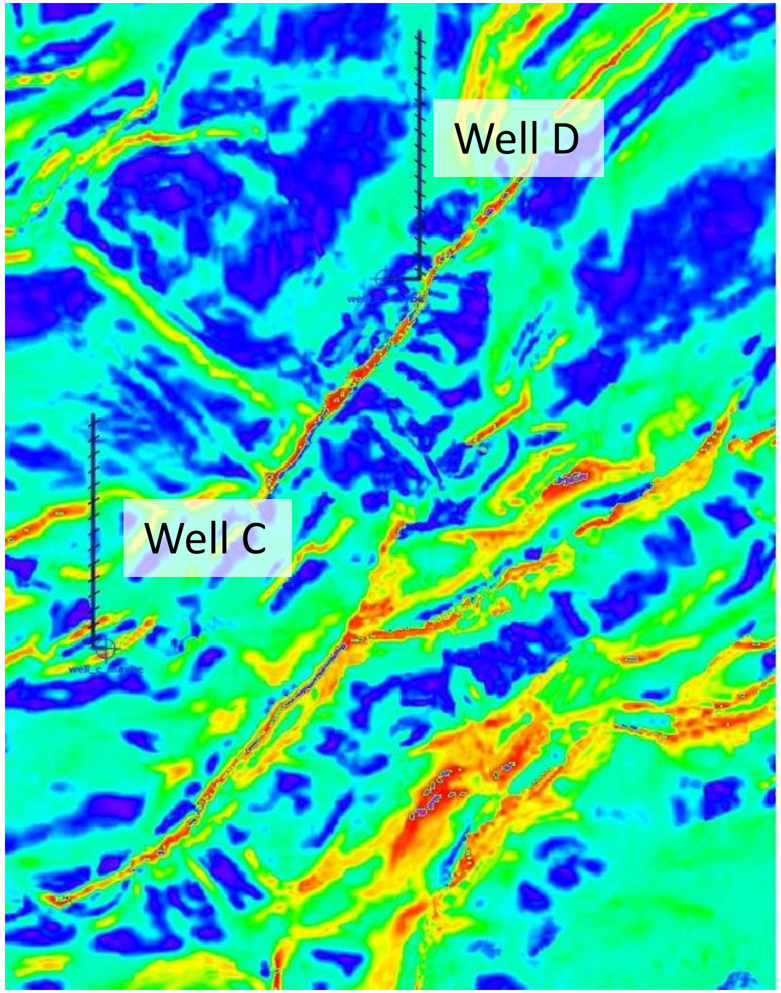
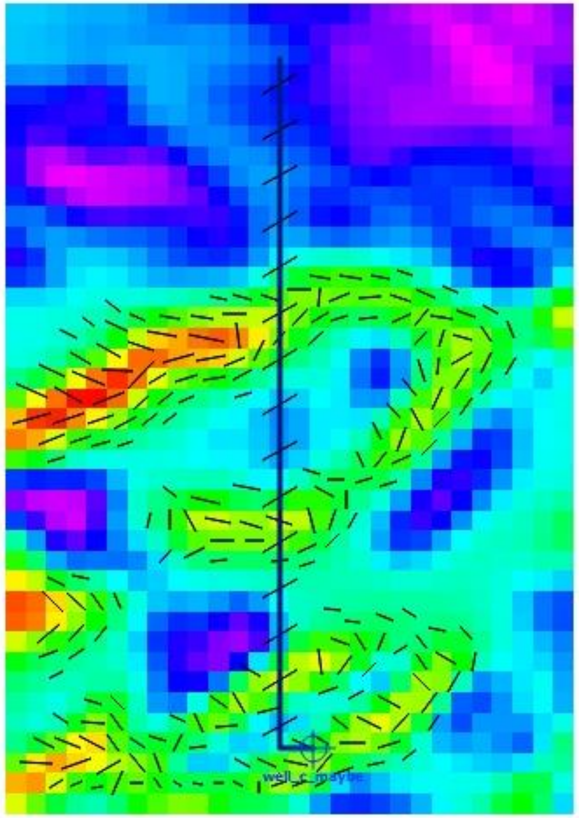


Figure 3: A) Dip azimuth (0-360 degrees) top Buda. B) Dip angle (filtered 0-2 degrees) top Buda. Contours on both images are top Buda subsea ft, CI 100 ft (refer to figure 1). Numbers denote examples of main structural features that are evident ; 1) Relay ramp transfer zone, SW dipping ramp with orthogonal (S_{Hmin} parallel) fault/fracture features 2) Regional (S_{Hmax} parallel) through going large displacement normal faults (note dashed black lines), 3) Transfer zone with regional SE dip, 4) Steeply dipping monocline.

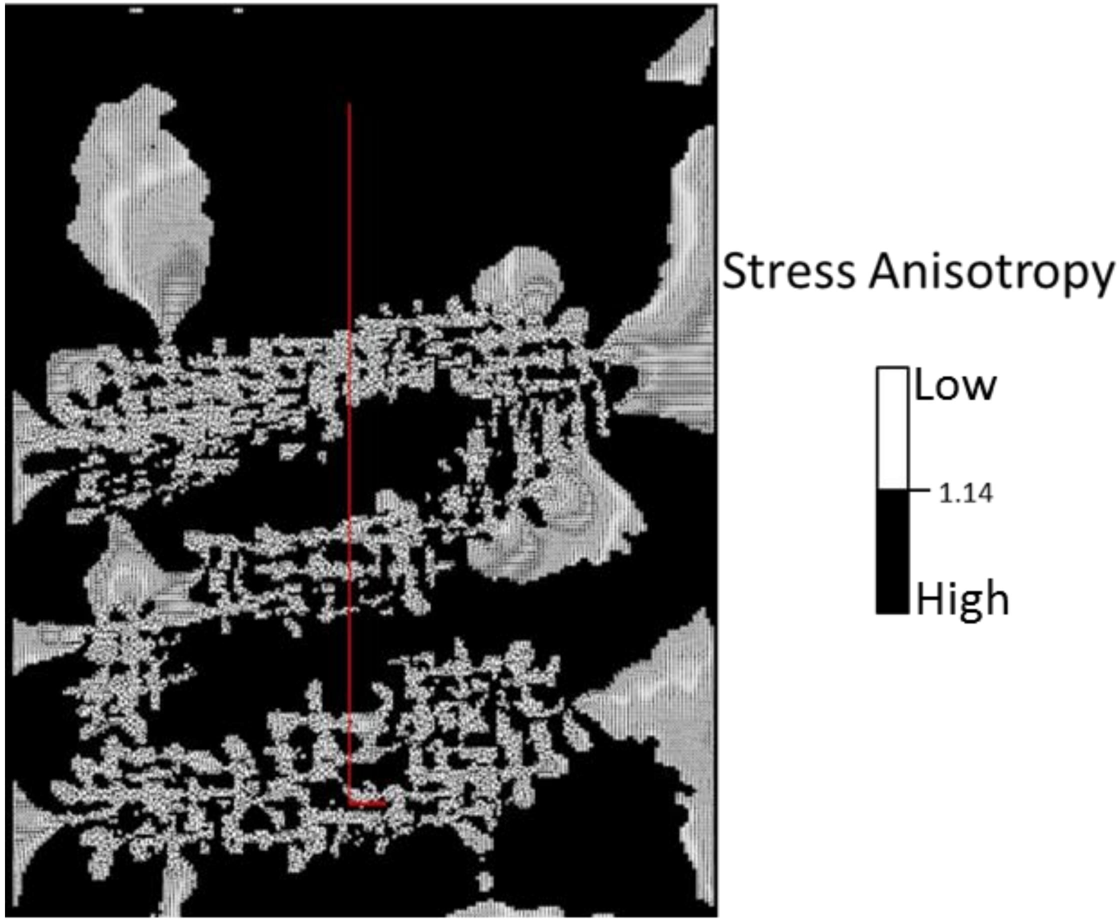
Application to an Eagle Ford dataset



URTeC 2148347



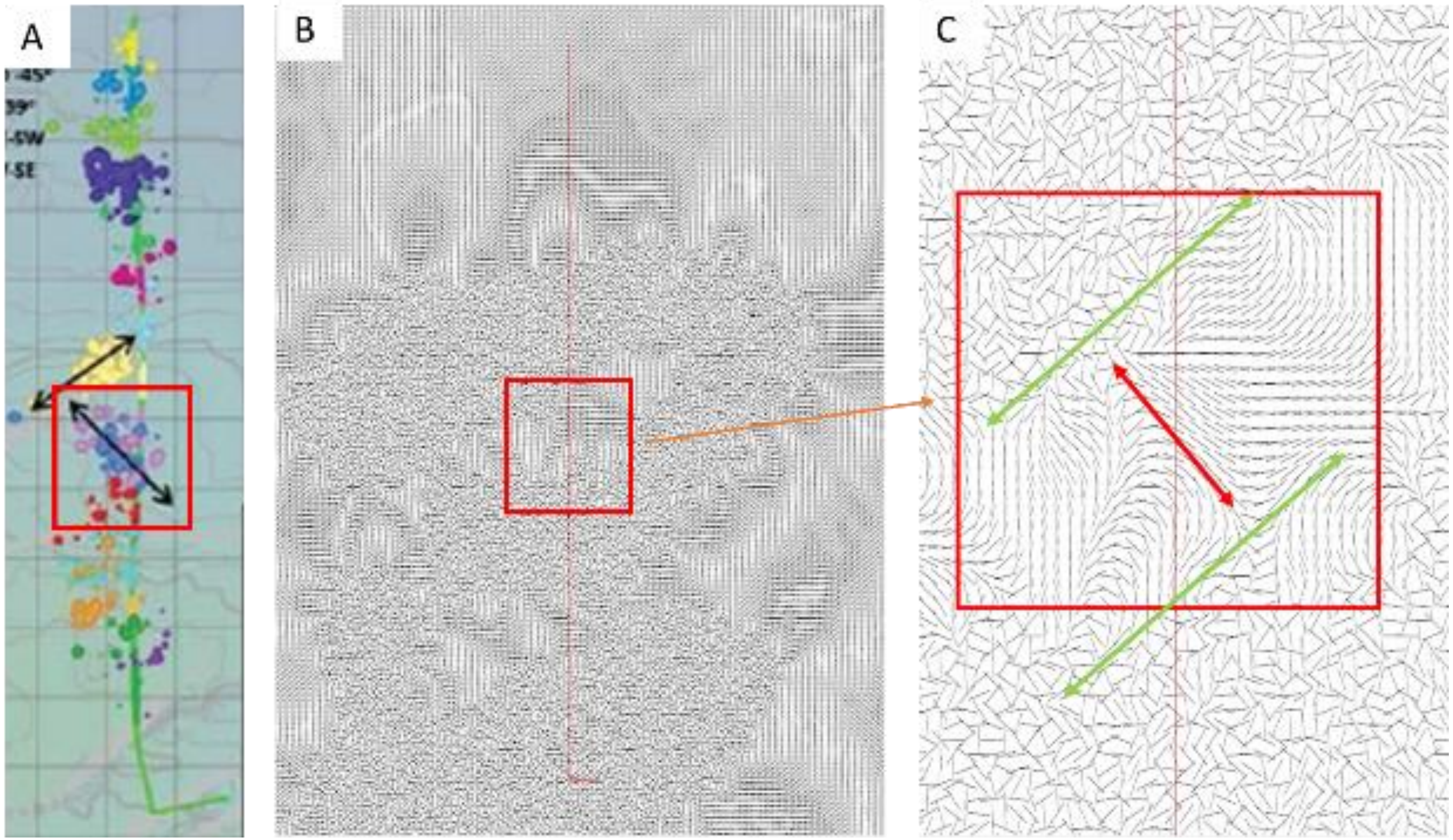
Well C



Well C

SPE 176932

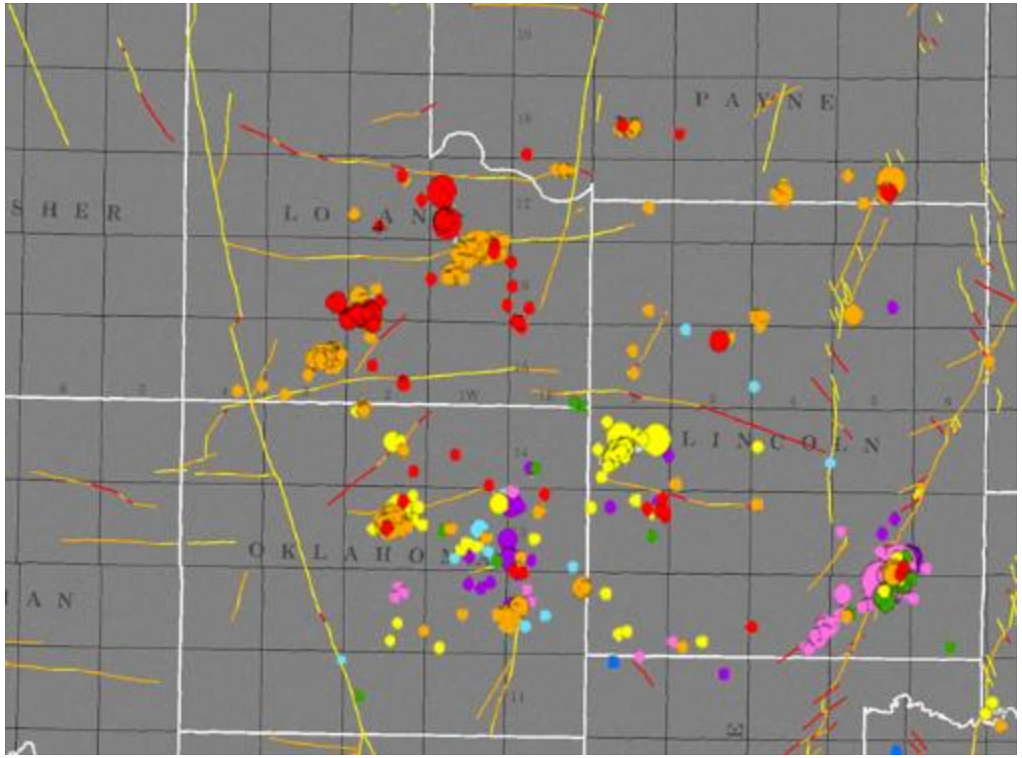
Stress Rotation in an Eagle Ford Well



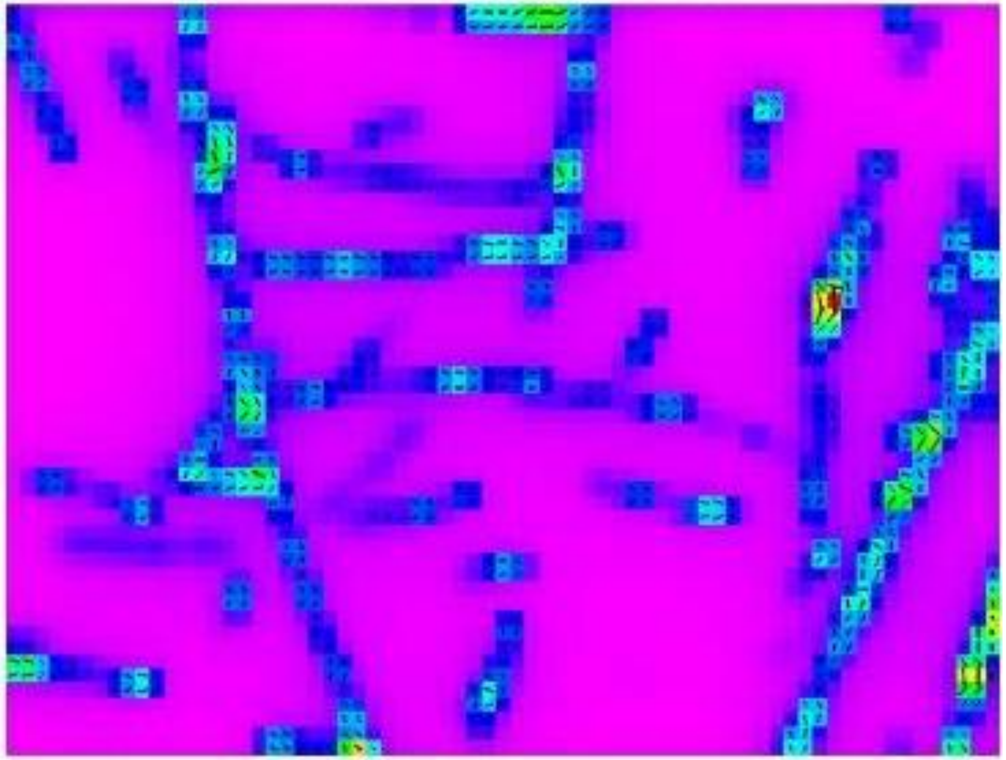
URTeC 2148347

SPE 176932

Oklahoma Induced Seismicity

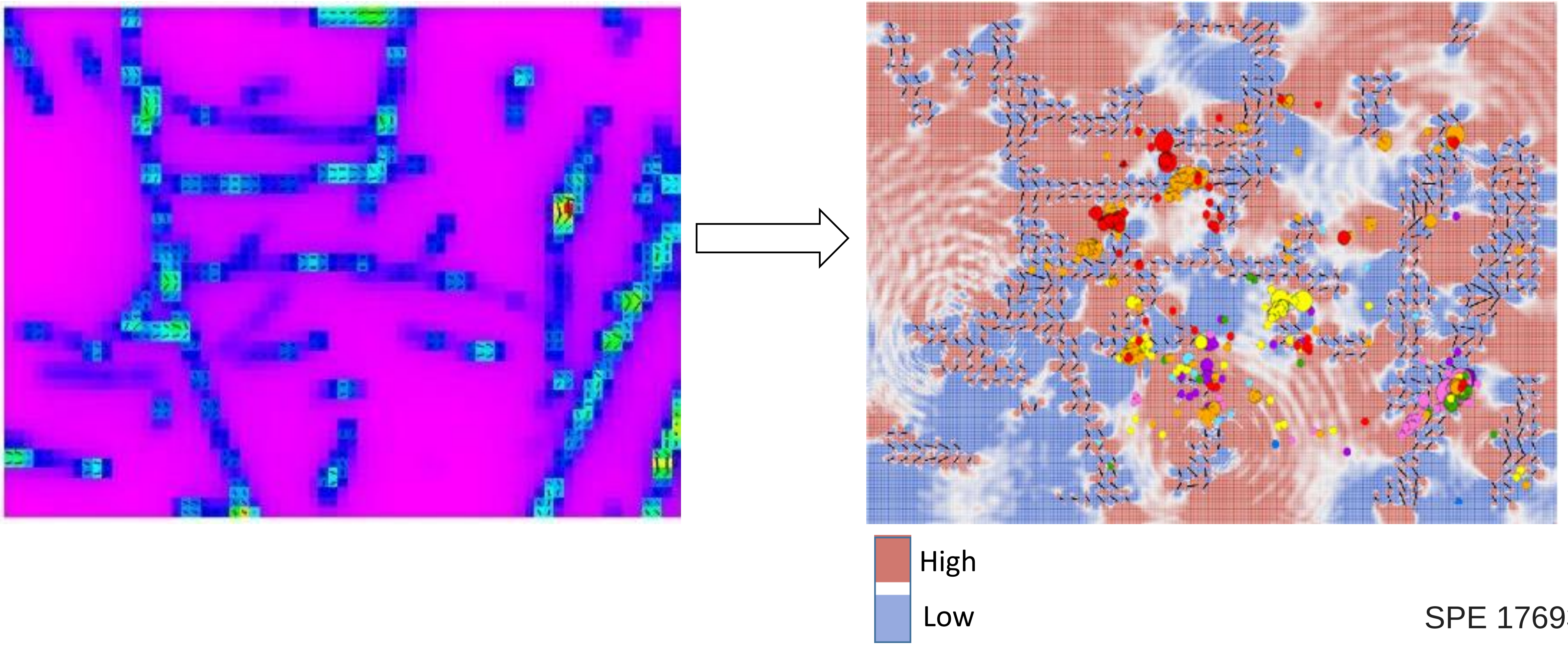


Modified from Oklahoma Geologic Survey



SPE 176932

Can geomechanical modeling predict induced seismic events?



SPE 176932

Results

- The use of the MPM and CFM technology to account for the interaction between hydraulic and natural fractures provides practical and quick completion optimization tools

- Quantifying the impact of natural fractures on fracing and subsequent well performance may:
  - Reduce stage inefficiencies
  - Avoid remediation/faults
  - Predict changes in the local stress field
  - Predict zones with a high potential for induced seismicity?

Thank You!

FracGeo