STRENGTH

STRENGTH IN LEADERSHIP

Integrated Approach to Fracture Design

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Overview

- Ultra low permeability shale reservoirs require large fracture networks to maximize well performance
- These large networks are approximated with a 3-D volume of the recorded microseisms in the reservoir called a Stimulated Reservoir Volume (SRV)
- Fracture simulators do a poor job of modeling fracture complexity

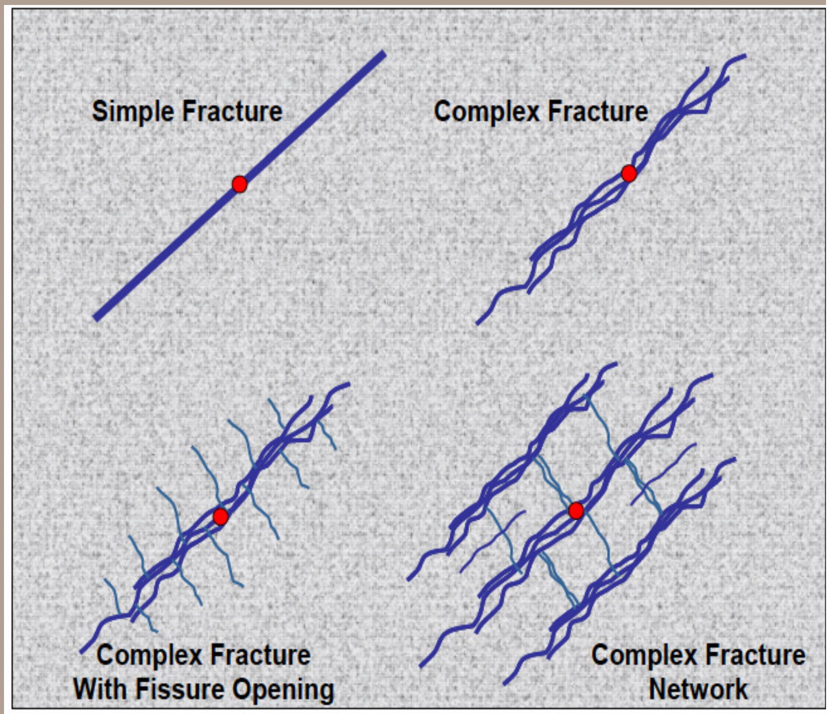
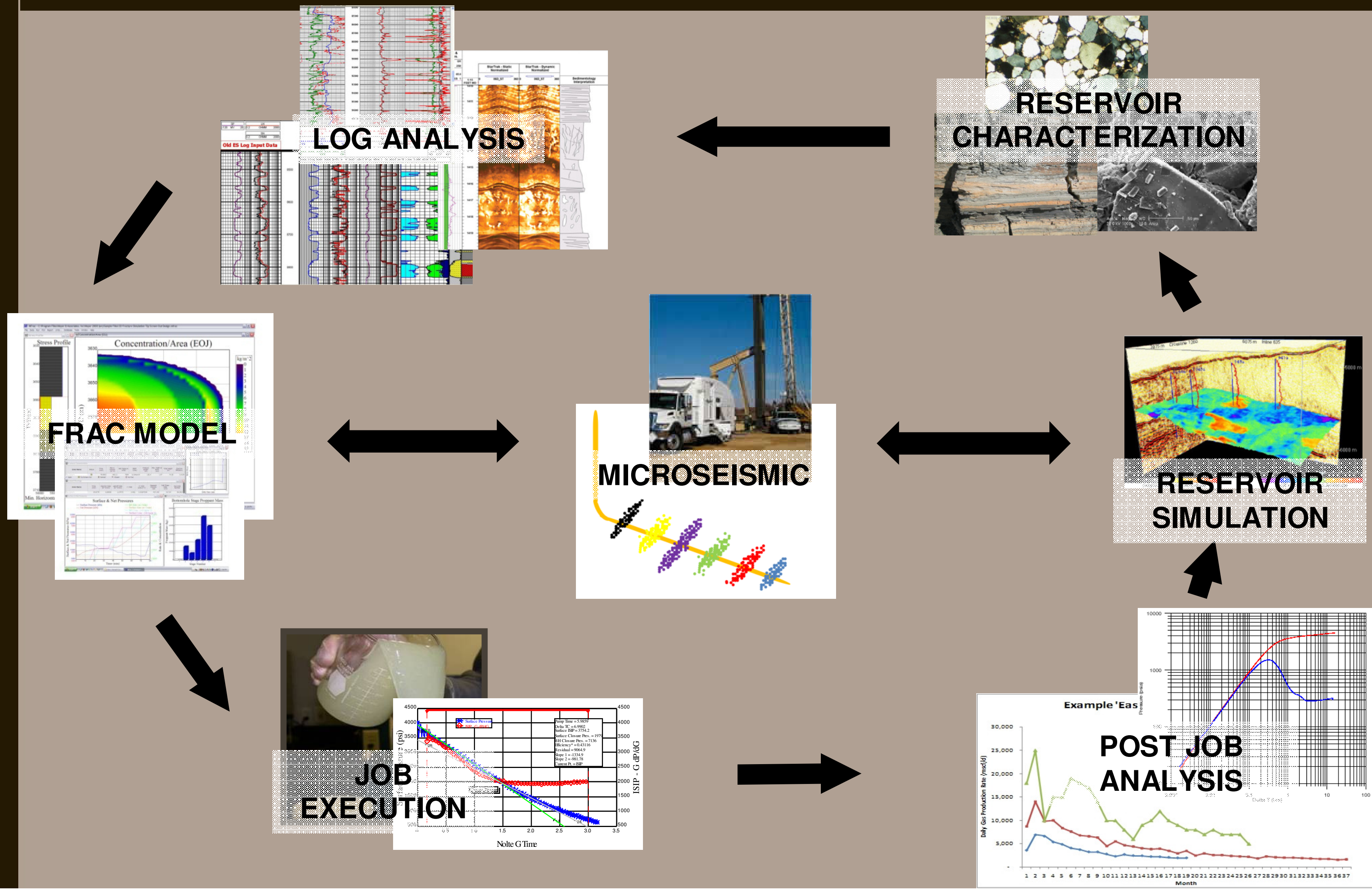


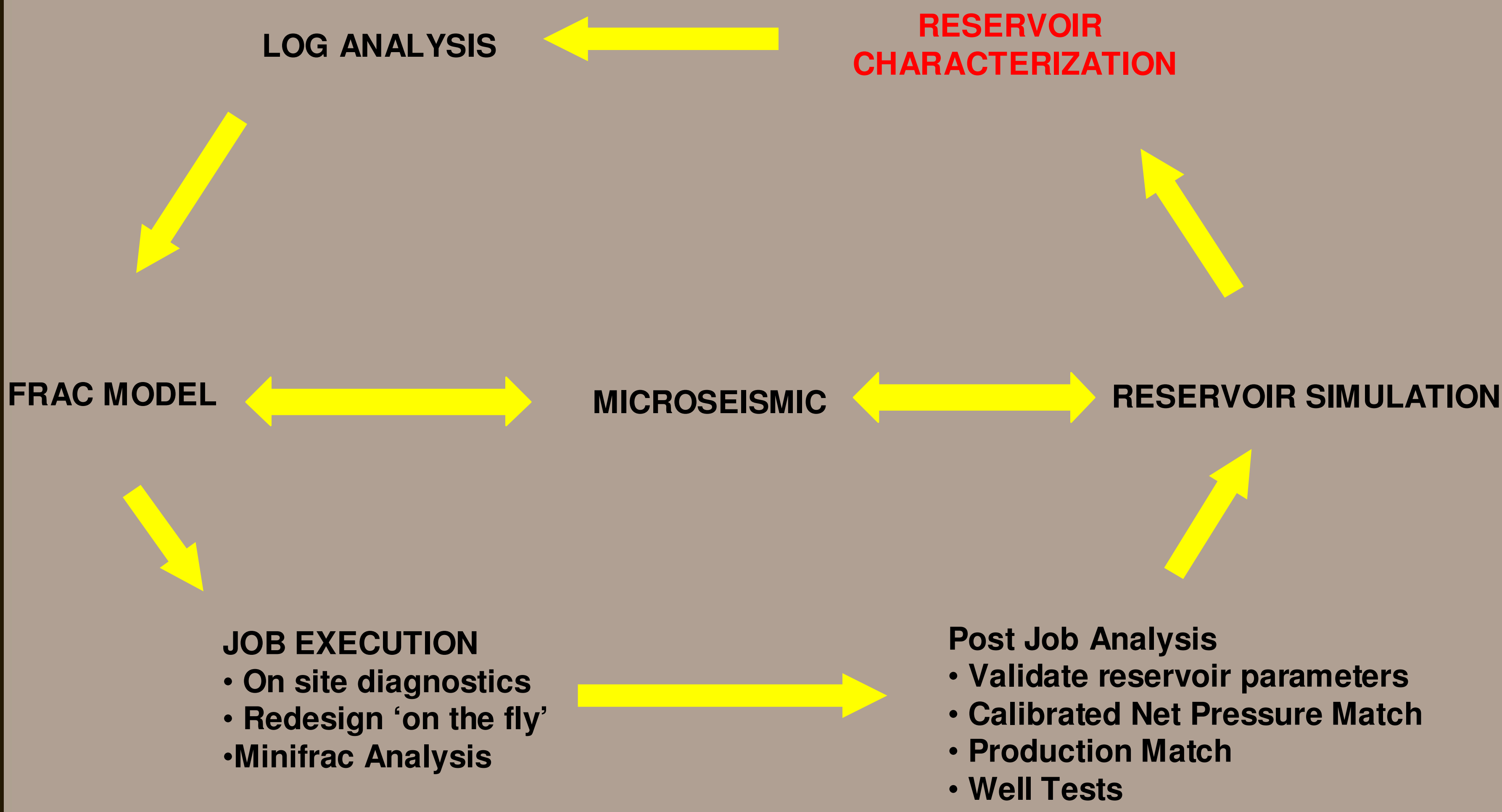
Figure from SPE119890

- Integration of microseismic data into a numerical reservoir simulator is proposed as a method to deal with the inaccuracies of modeling slickwater treatments in shale gas reservoirs

Integrated Optimization Process



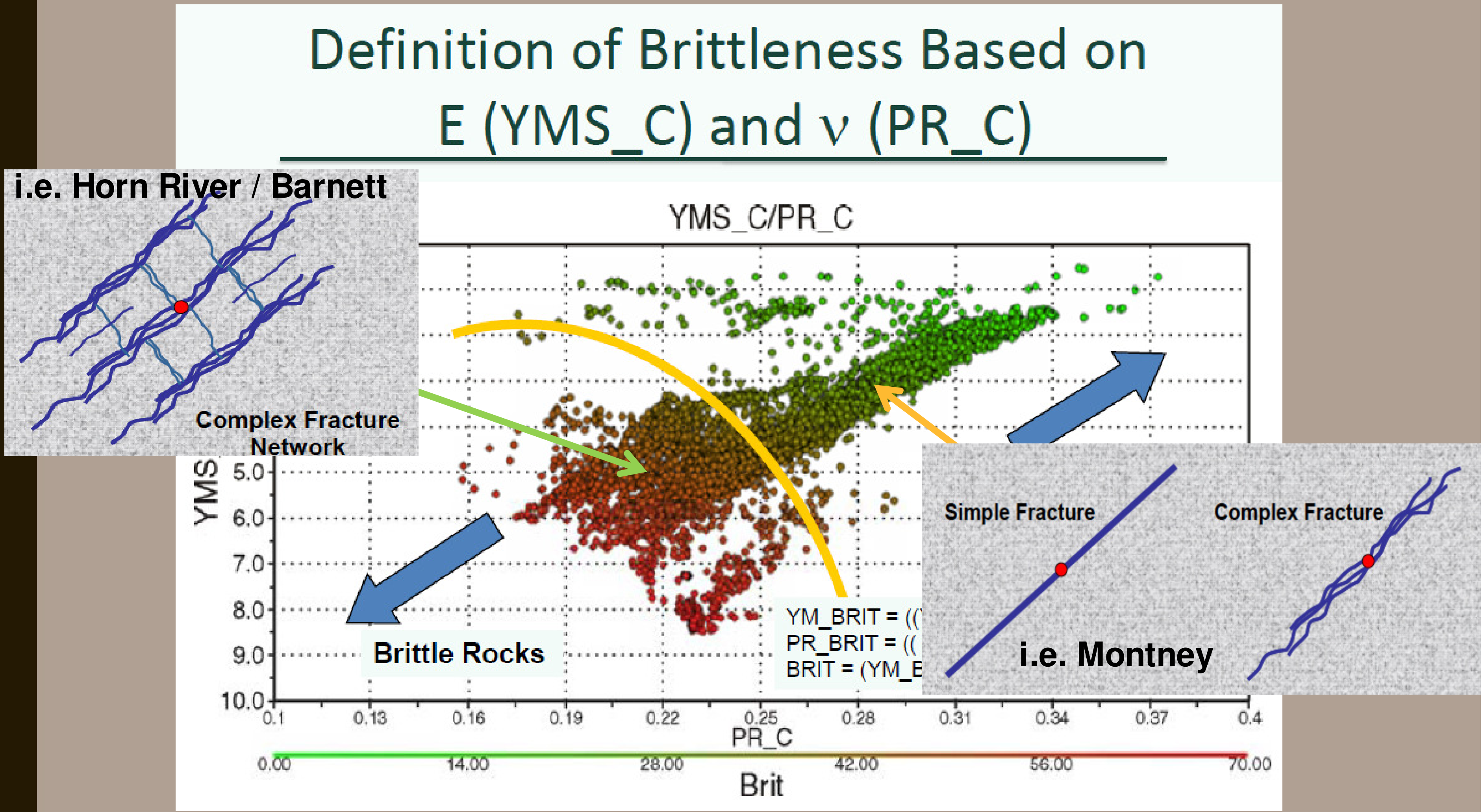
Integrated Optimization Process



Possible Analyses for a Shale Gas Reservoir

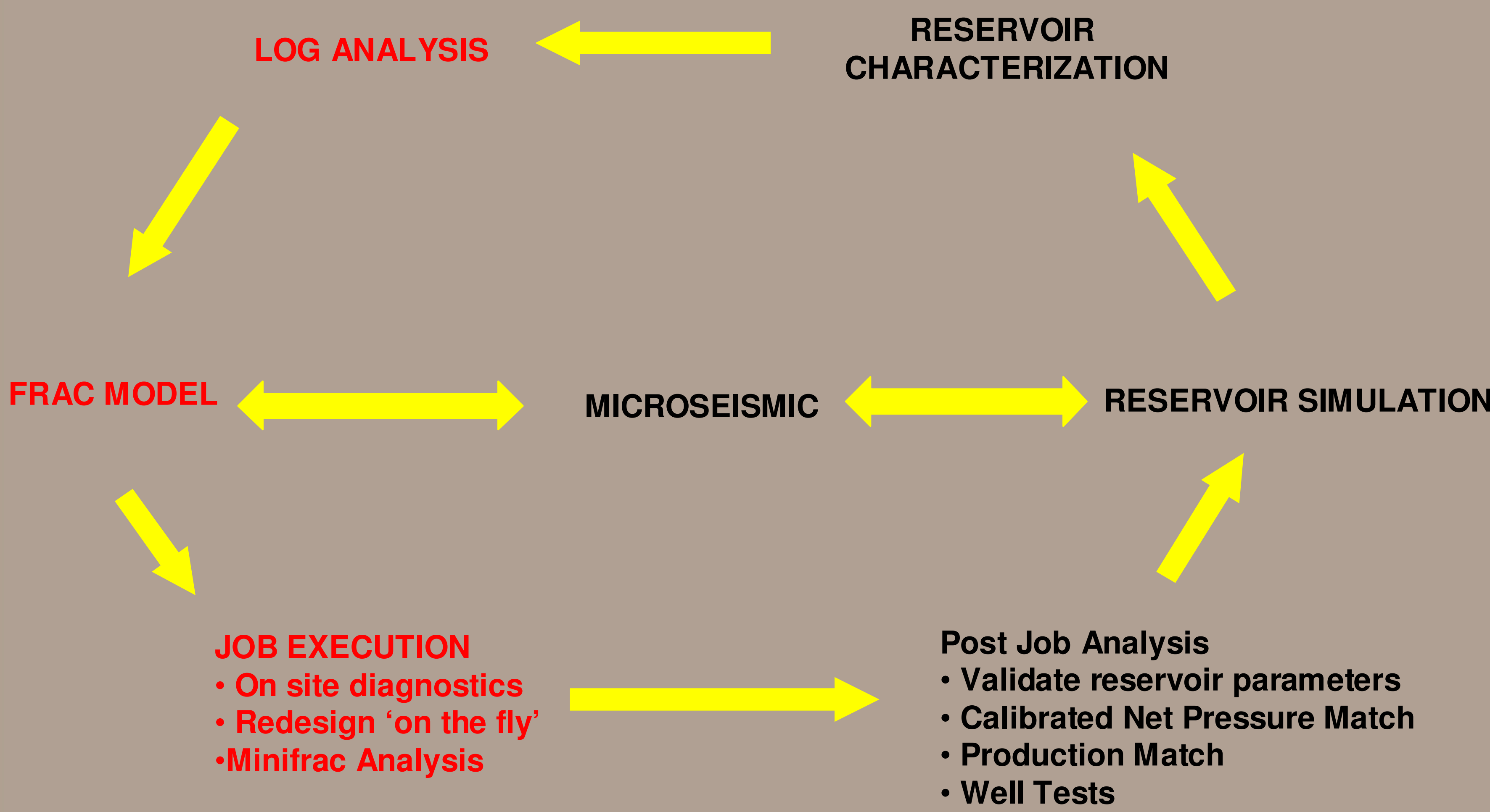
- Shale
- Mapping TOC
- Area
- Wireline Logs
- Maturity
- Thickness
- Stress
- TOC
- Geochemistry
- Maturity
- Gas Capacity
- Young's Modulus
- Absorbed Gas
- Moisture
- Temperature
- Rock Mechanics
- Free Gas
- Solution Gas
- Poisson's Ratio
- Pressure
- Al_2O_3 fraction
- Deliverability
- Matrix Permeability
- Fracture Permeability
- Porosity
- Sedimentology
- Fracturing
- CaO
- Slica contents
- Mineralogy
- Diagenesis
- Coarser horizons

How is the rock going to break?

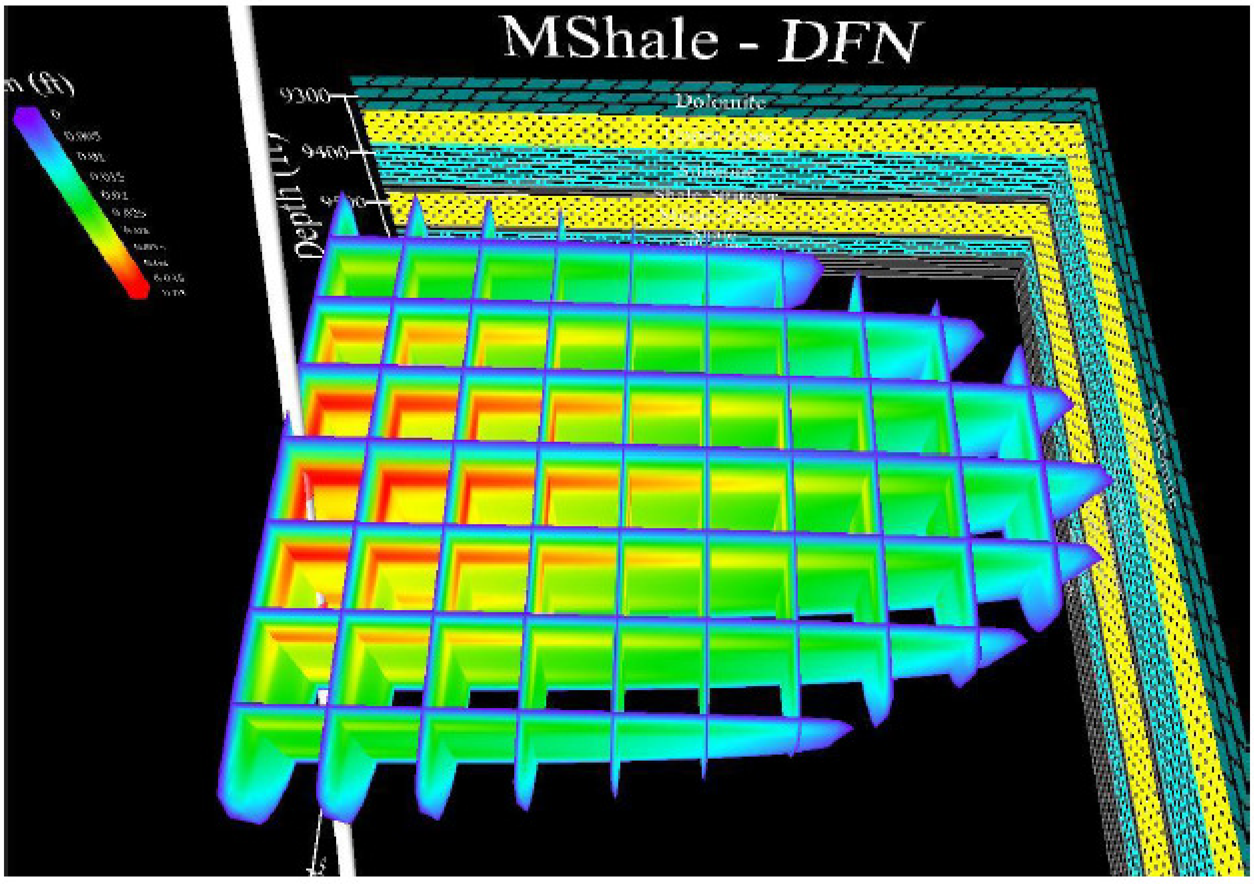


Barree Presentation

Integrated Optimization Process



Frac Model of Shale Simulation



Meyer's and Associates Website

- Difficult to accurately model shales in a frac simulator
- A good tool when integrated with microseismic data

Integrated Optimization Process

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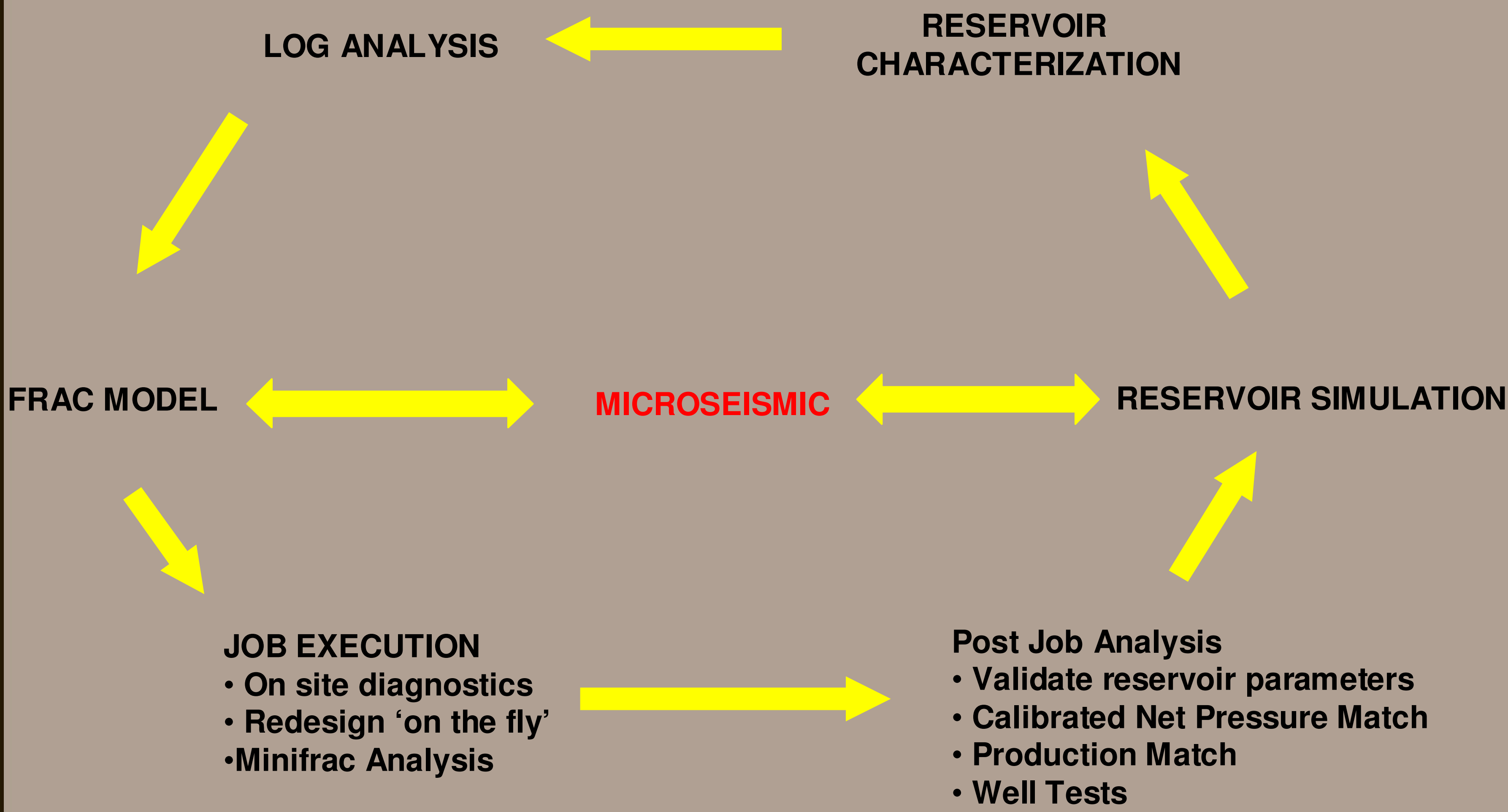

Information that Collecting a Microseismic Dataset Provides

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Fracture Azimuth

Fracture Length

Fracture Height

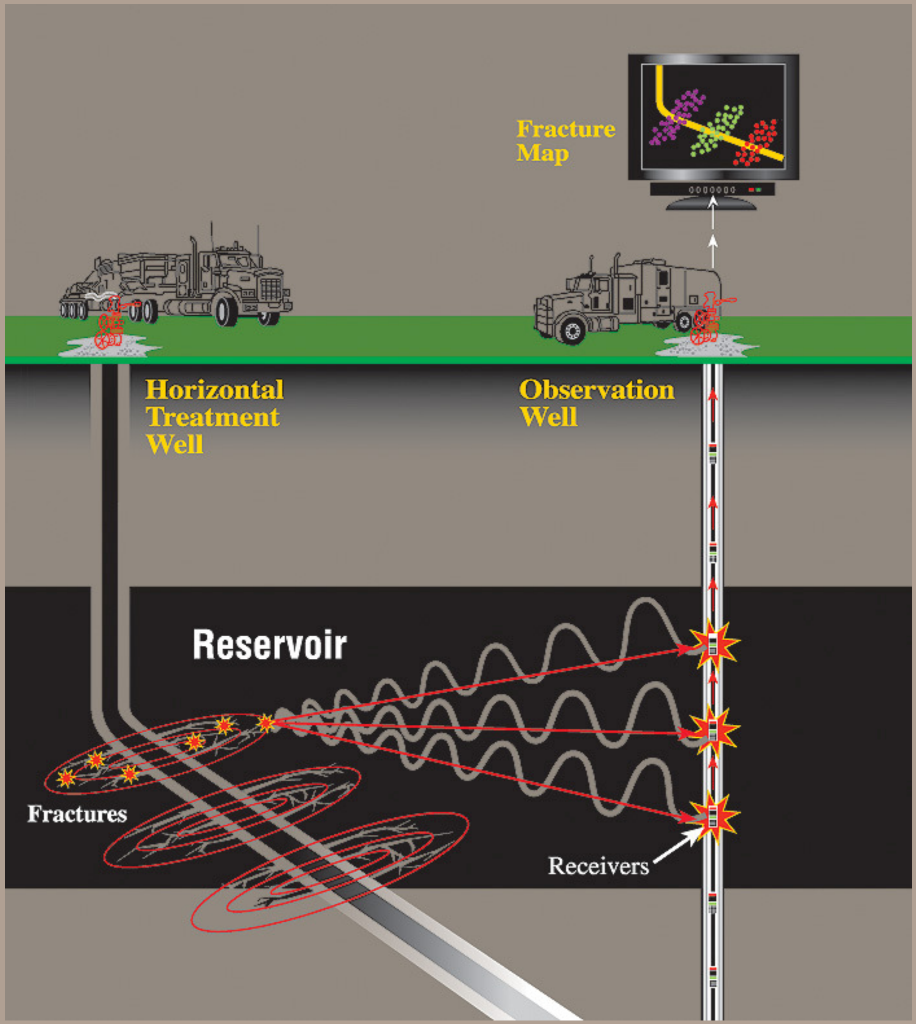
Fracture Complexity

Calculation of Stimulated Reservoir Volume

Evaluation of the effectiveness of the completion system

Calibrated Fracture Modeling and Integration of Microseismic into a Reservoir Simulator

Project Set-up



Array of 12 or more geophones in an offsetting wellbore is used to locate microseismic events in the frac well

Each geophone has 3 components (x, y, z directions)

Determining Distance from Geophones to Microseismic Event

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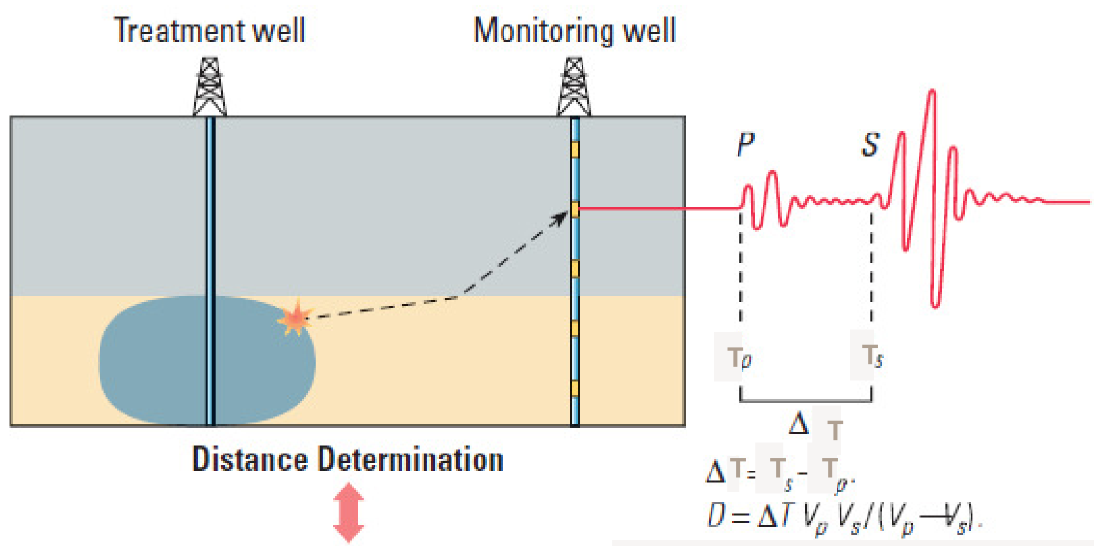
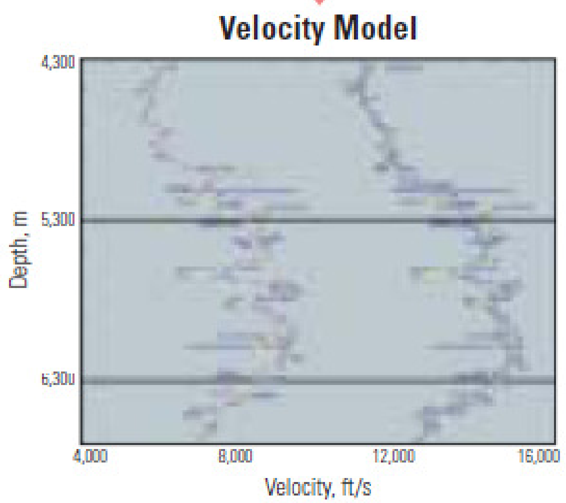




T_p and T_s = arrival times of the P wave and S wave

V_p and V_s = velocities of P wave and S wave in each layer of the velocity model

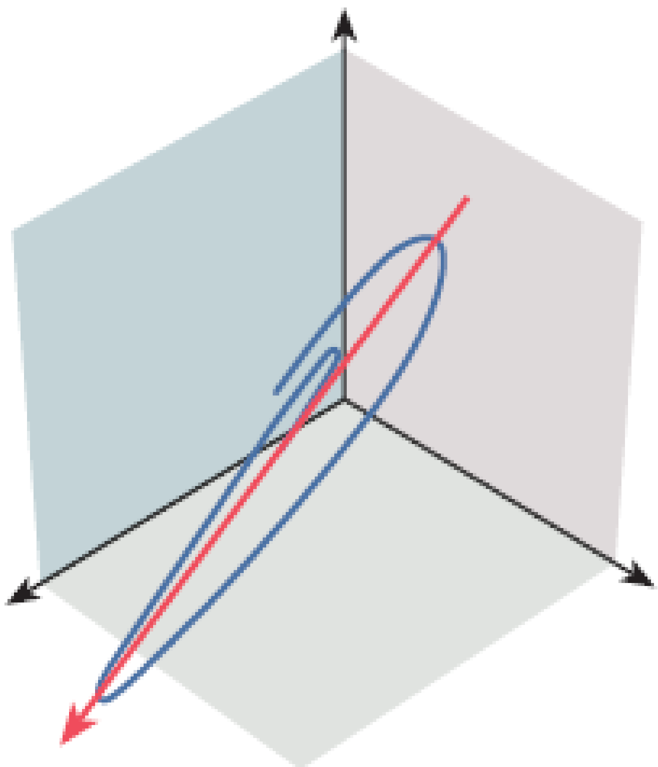
D = distance to the microseismic event

Determining the distance (D) to the event is derived by measuring the arrival times of the P and S waves for a microseism

Velocities of the P and S waves in the rock are determined by the velocity model (a dipole sonic log can provide these velocities)

Oilfield Review Winter 2005/2006

Determining Angle from the Geophones to the Microseismic Event



Azimuth-Angle Determination

Oilfield Review Winter 2005/2006

A hodogram is used to examine the particle motion of the P-wave to get the azimuth to the microseismic event

In a cylindrical co-ordinate system if you know the distance to the event and the angle to the event, the event can be located in 3-D

Moment Magnitude Plot

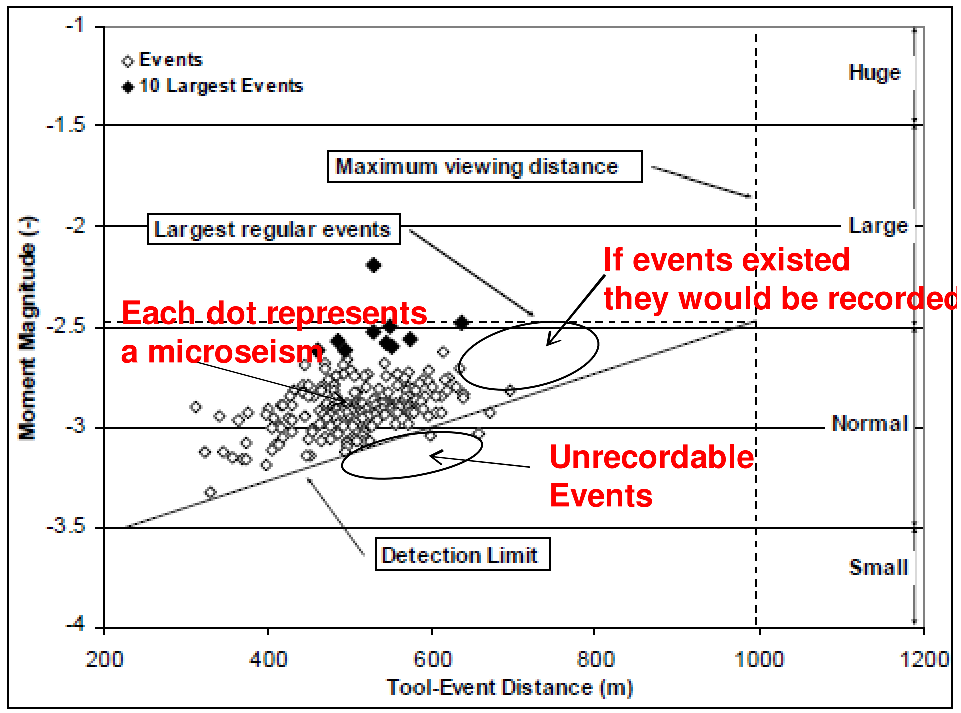
This plot will help understand if an observation well is close enough to the frac well for a project to be successful.

Y-axis is moment magnitude (like Richter Scale) and is a measure of the size of the event

X-axis is the distance from the geophones to the microseism

The closer the geophones are to the microseisms the more events recorded

Slurry rate and volume & rock type have a bearing on this graph

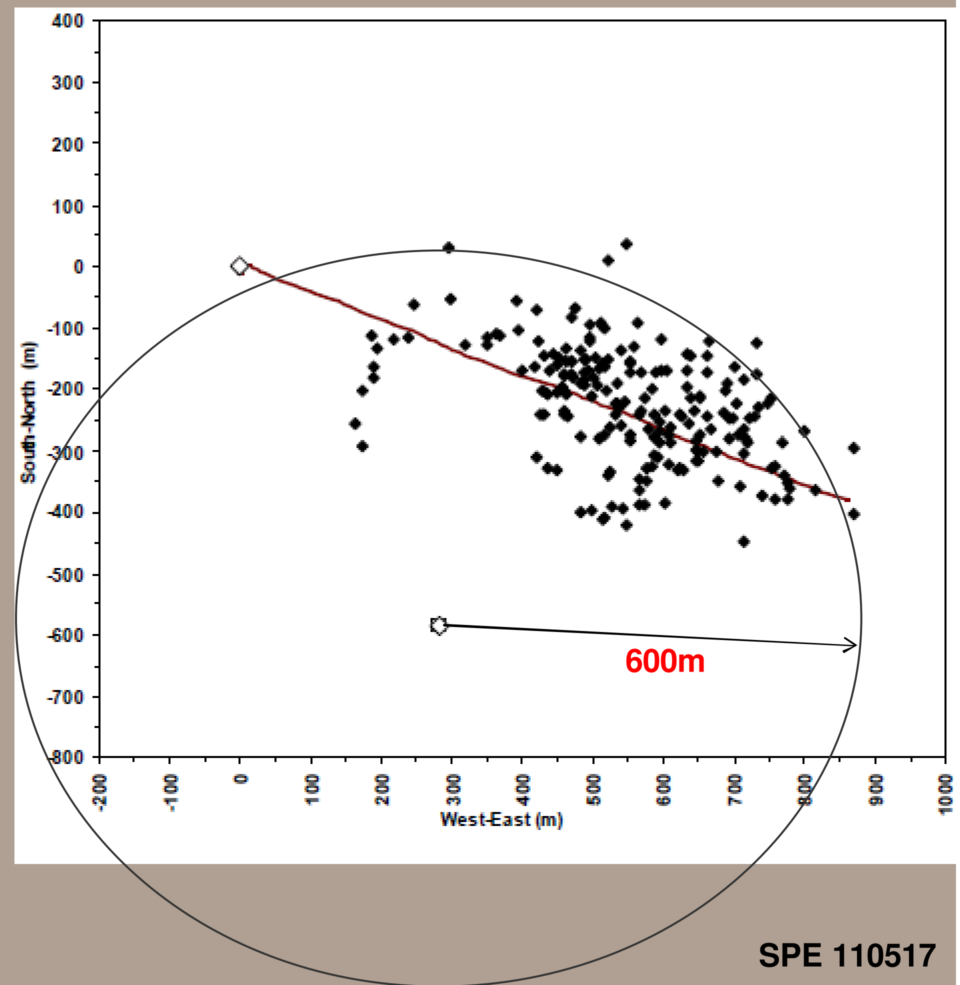


SPE 110517

Understanding Observation Distances

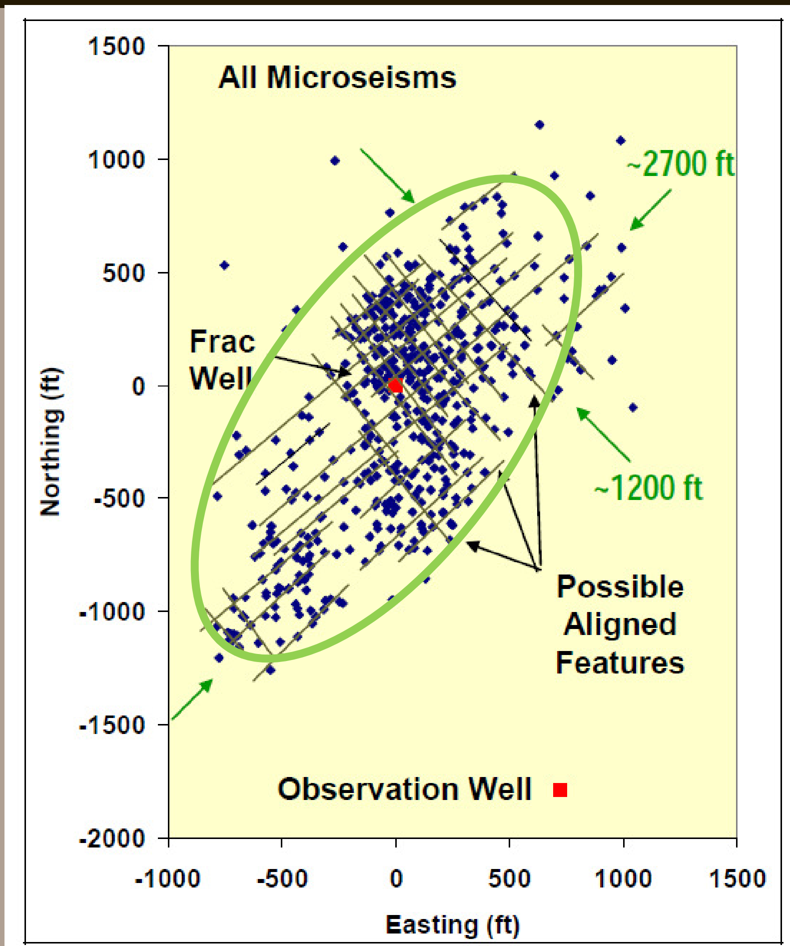
Comparing this event cloud its moment magnitude plot we can see that the fracture has been well imaged

The microseisms represent the fractured area well

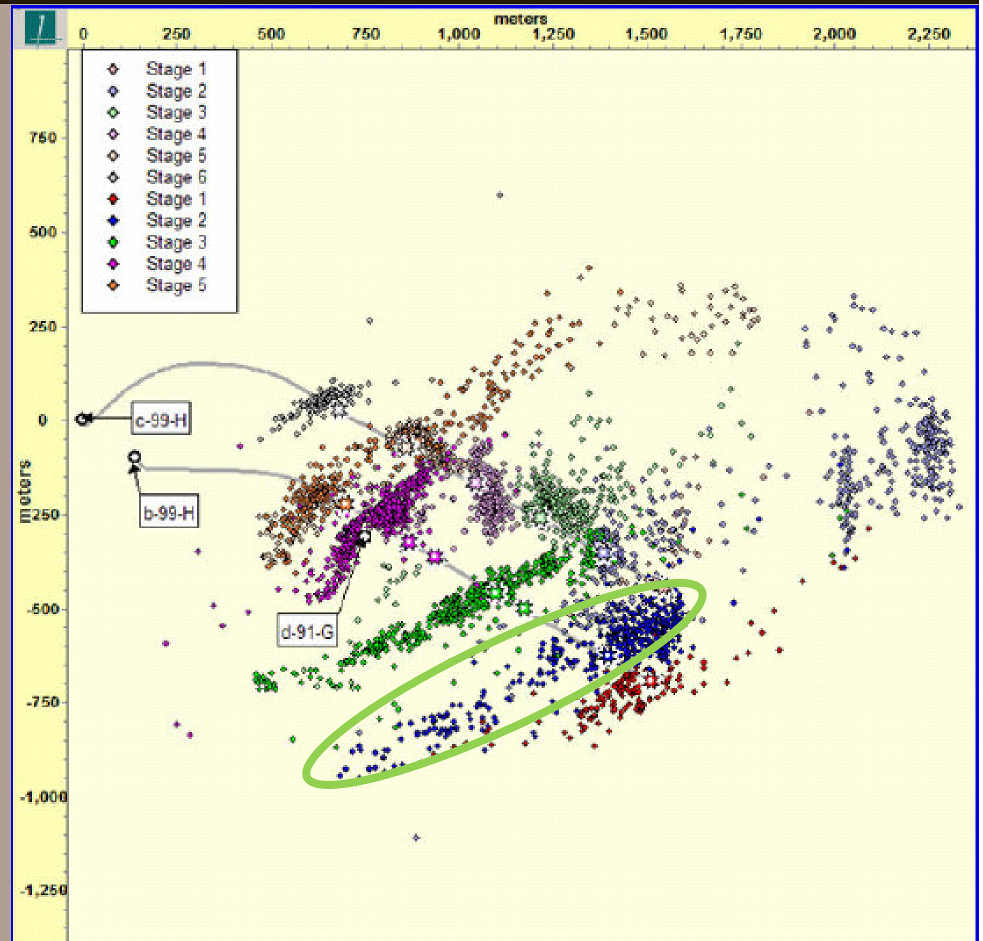


SPE 110517

Microseismic Images from Shale Gas Reservoirs

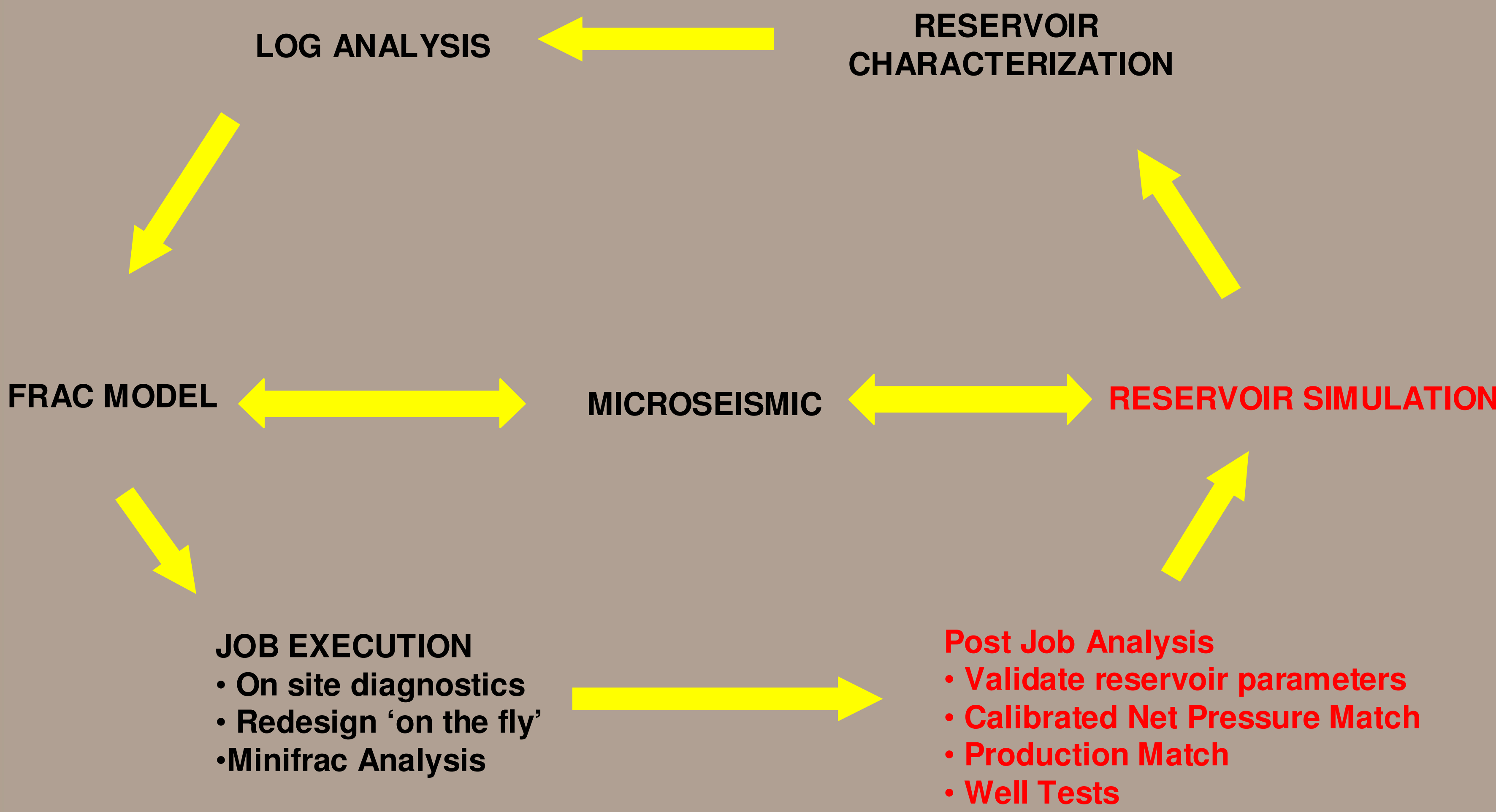


Barrett Shale from SPE 114173



Horn River Basin from Apache Website

Integrated Optimization Process



Post Job Analysis

Important step to increase the efficiency of subsequent treatments

- Validates and improves engineering models

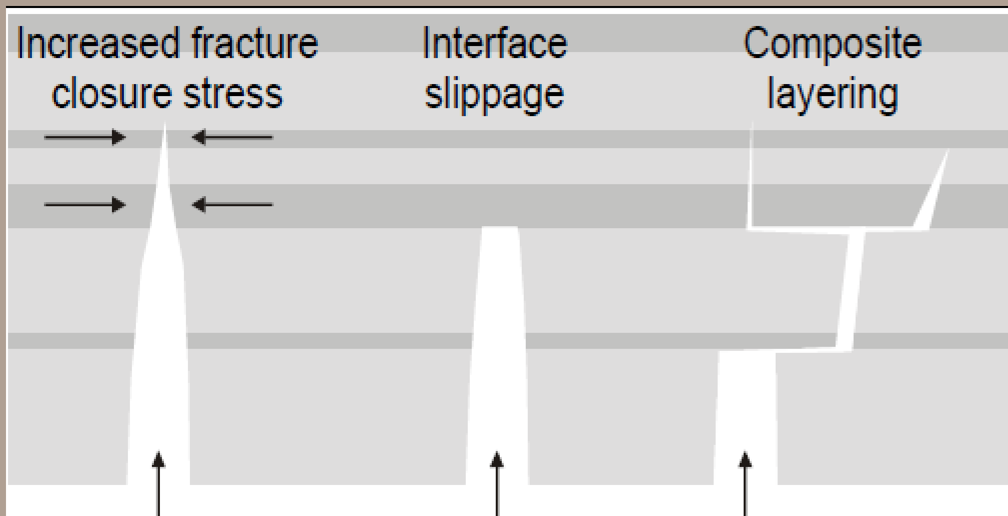
Production matching

Integration of well tests, tracer logs, production logs if the data has been collected

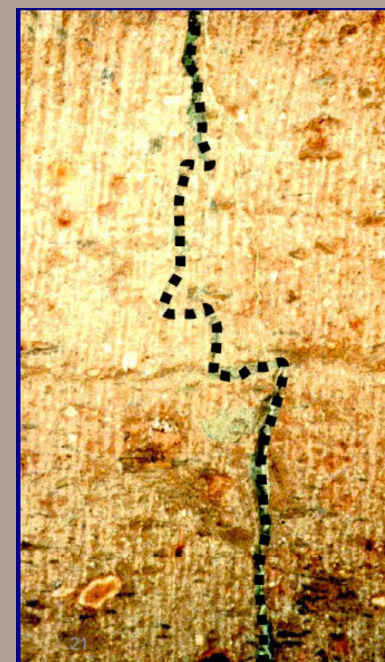
Net pressure matching where applicable

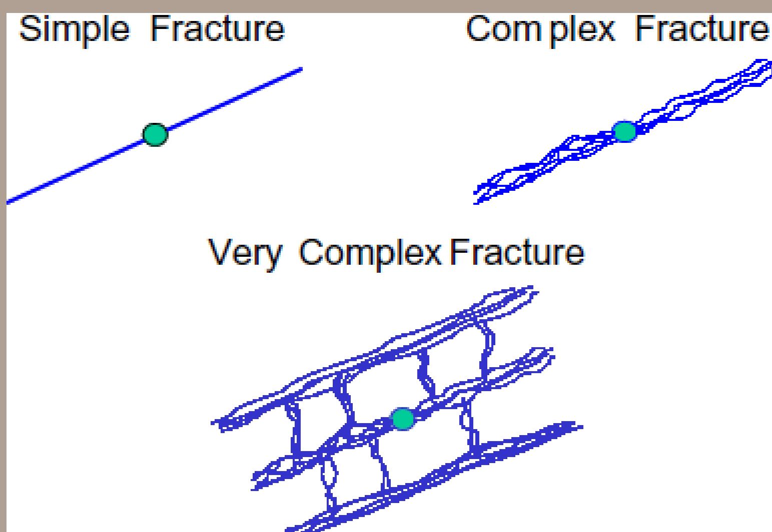
- Calibrated matching if there is microseismic data

Calibrated Fracture Models



SPE 96080





Microseismic mapping has shown us that conventional frac modeling does not always predict fracture geometry

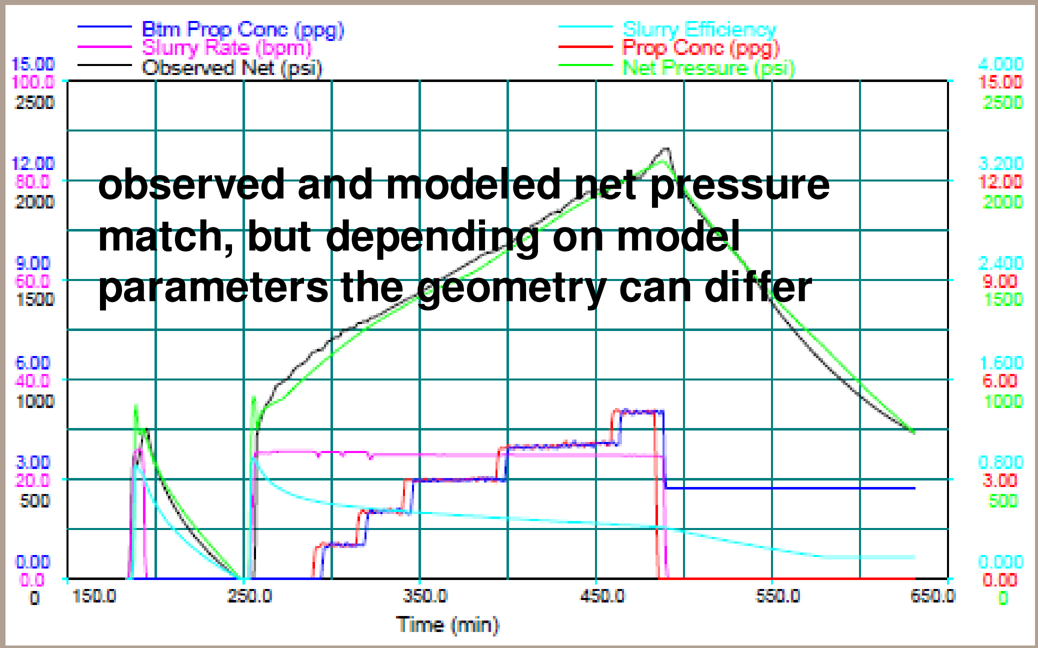
Calibrated fracture models are the result in planar frac systems

Calibrated Fracture Models

Net pressure history matches alone provide a non-unique solution

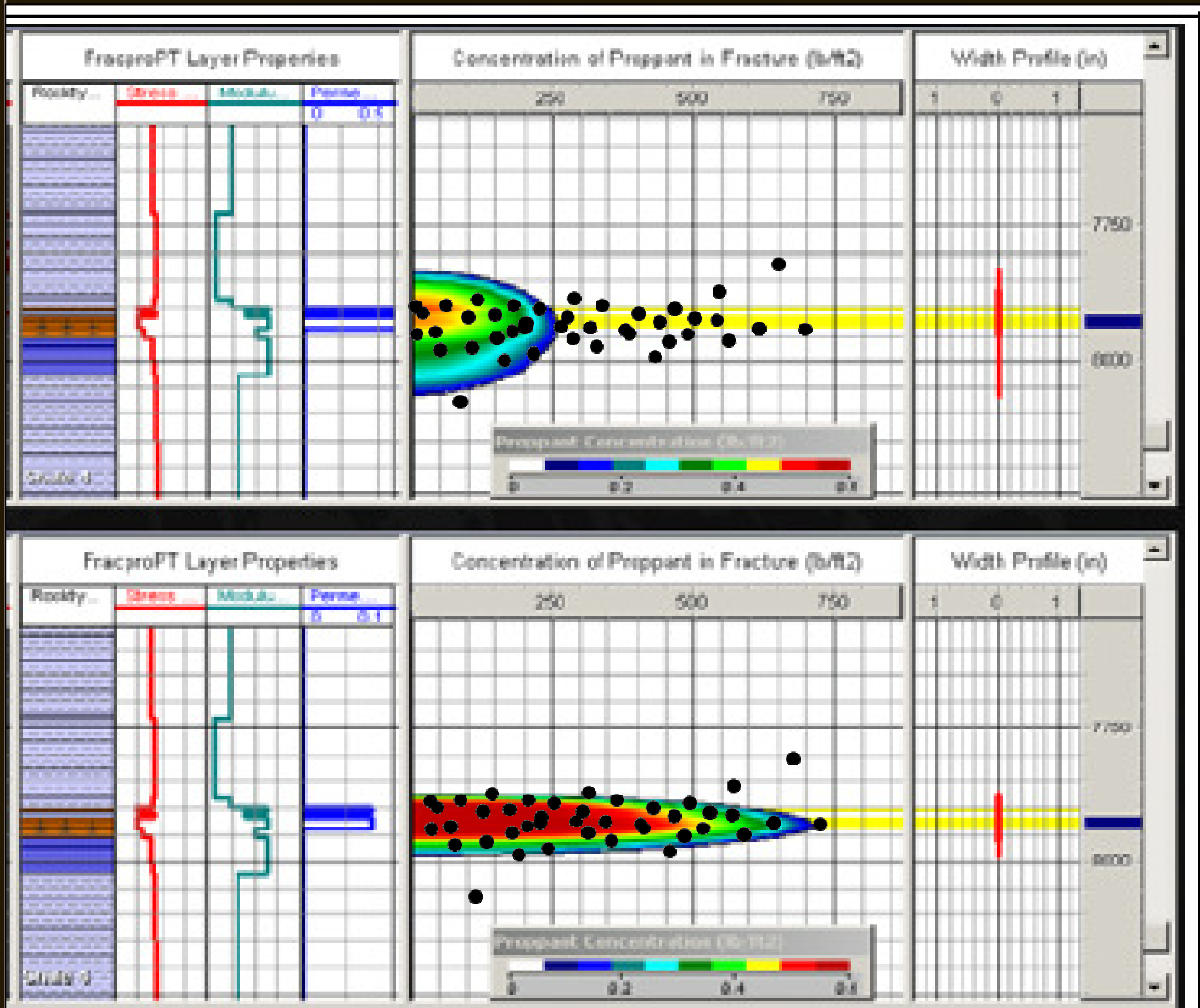
If microseismic data is collected on a project not only does the net pressure have to match, but the geometry from the microseismic must match too

- A calibrated frac model



Adapted from SPE 96080

Calibrated Fracture Models (Planar Fracture)

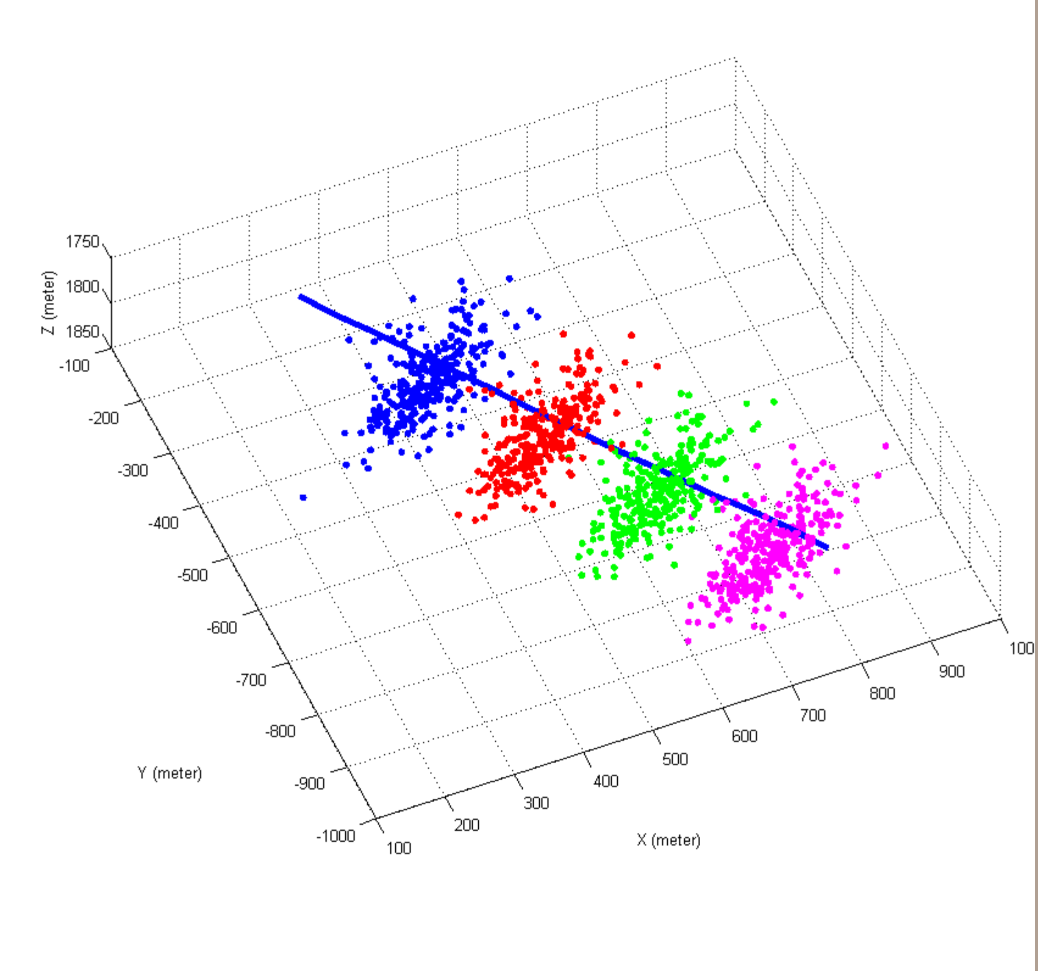


- Not Calibrated

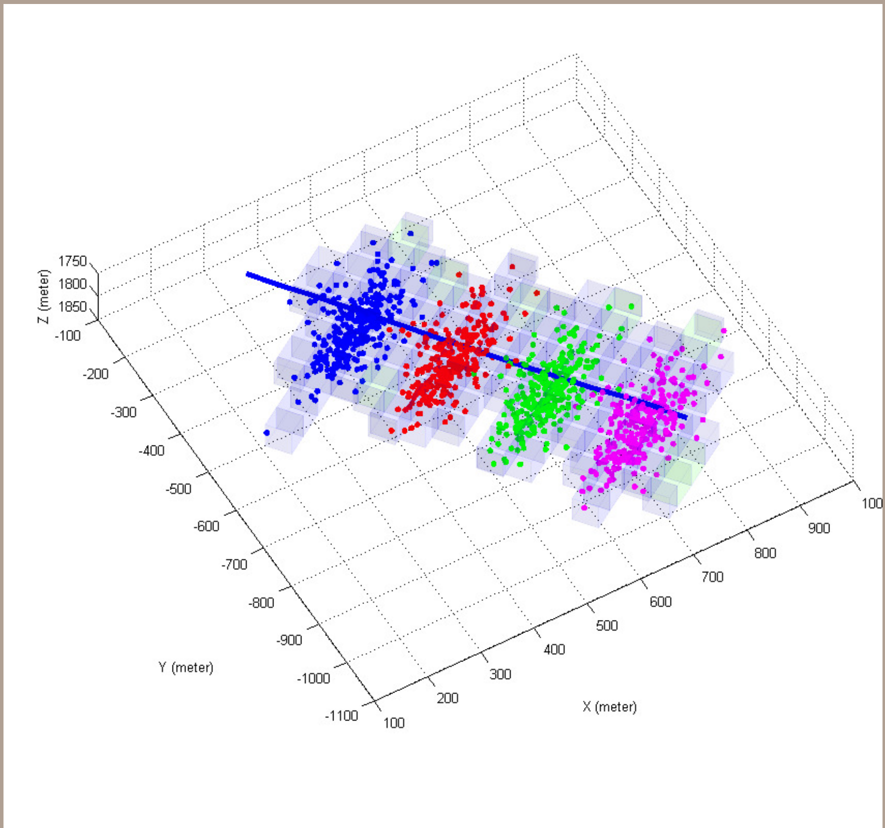
- Calibrated

Adapted from SPE 96080

Hypothetical Microseismic Data for a "Complex" Fracture System



Determination of Stimulated Reservoir Volume



Microseismic data from a give frac well is used to estimate SRV

Bins are drawn in in the principle fracture direction to the furthest event from the wellbore

- Bins are summed to get a SRA (stimulated reservoir area)

An estimate of stimulated reservoir height in each bin is a is made

- Microseism must fall inside pay height to be counted

SRV is calculated by multiplying the bin height by the area then summing

SRV and Well Performance

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Graphs showing a general relationship for 6 month and 3 year gas production

Larger SRV's in these well equate to greater production

Important to note – SRV does not indicate effectively producing portions of the fracture network or spacing in the network

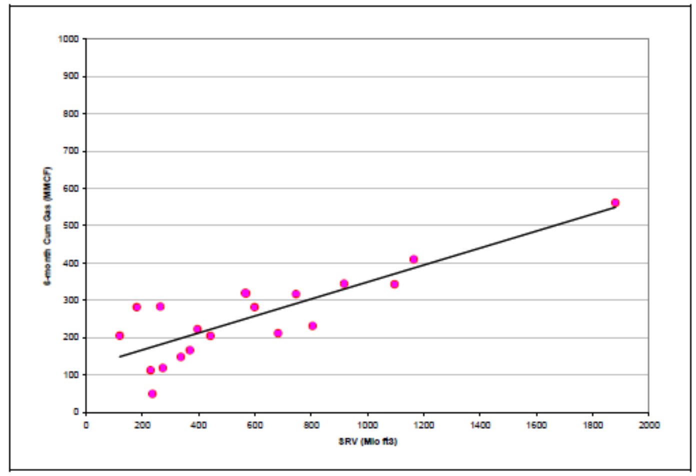


Figure 8. SRV trend versus 6-month cumulative horizontal well production for one Barnett shale county

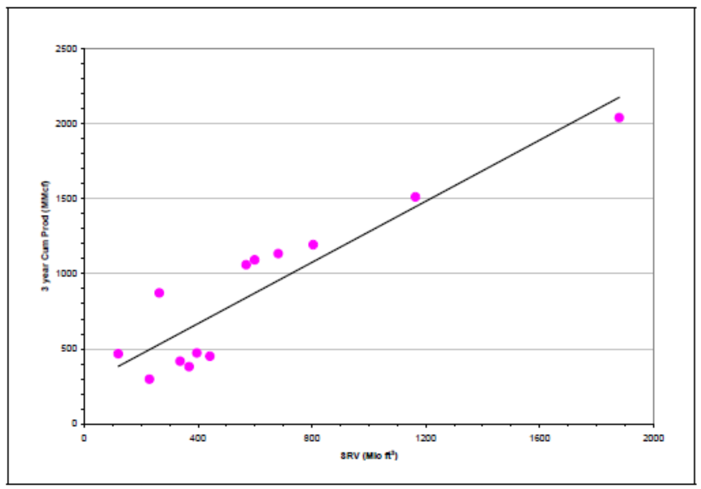


Figure 9. SRV trend versus 3-year cumulative horizontal well production for one Barnett shale county

SPE119890

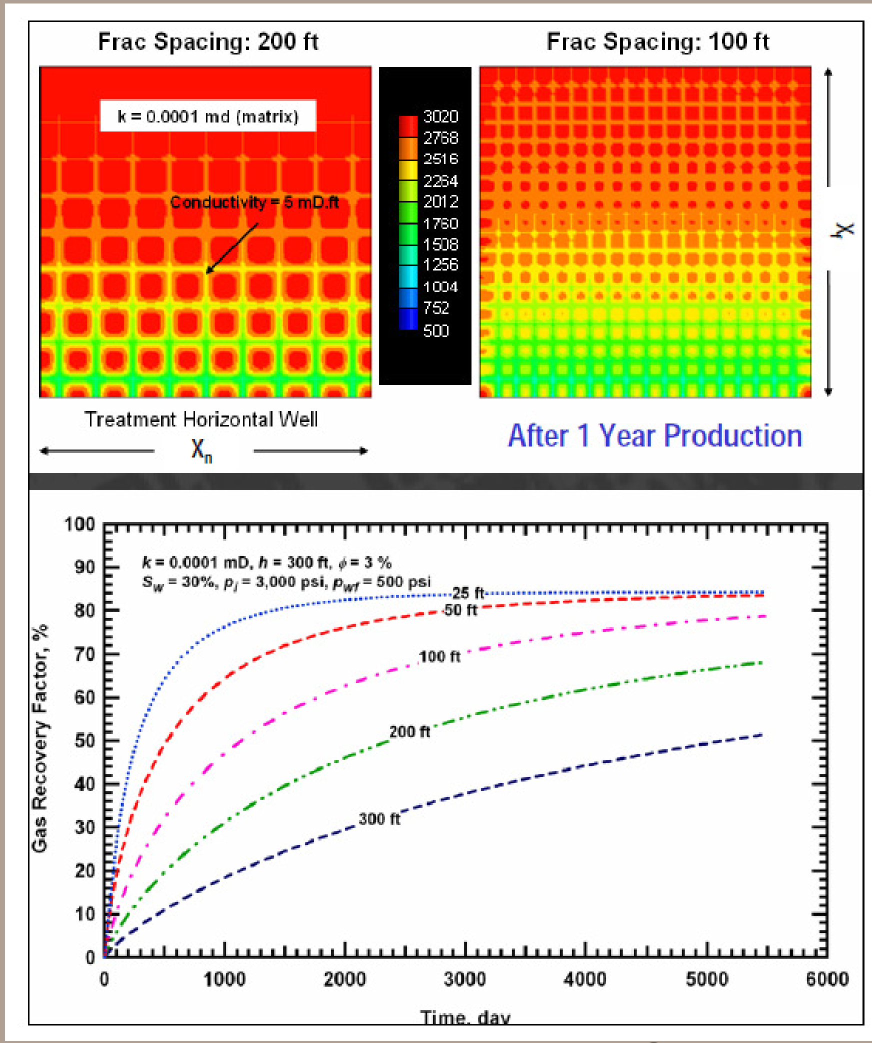
How does fracture spacing in the SRV affect production?

As fracture spacing inside the SRV gets tighter the production improves

Total fracture length increases as fracture spacing decreases within the SRV

Note how production is limited to the network in the simulation

- Due to ultra low matrix permeability



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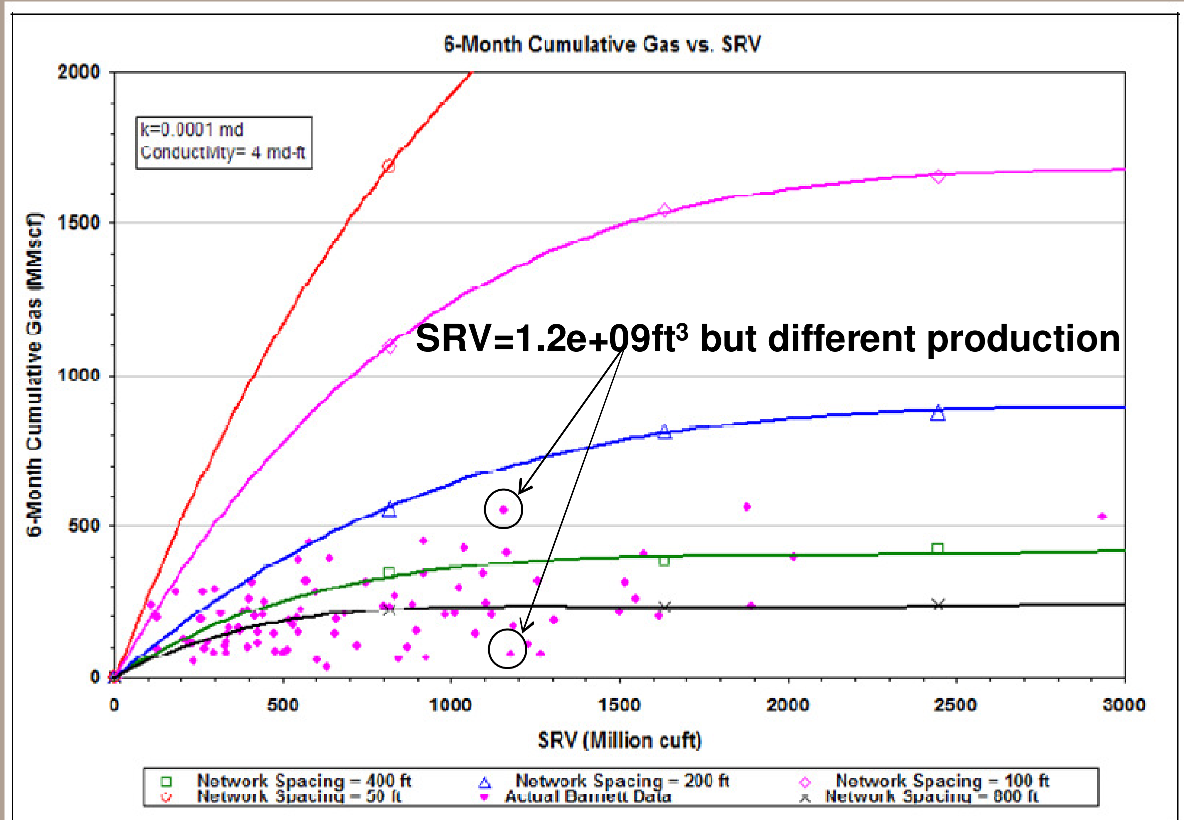
Actual Barnett Production

Graph shows how actual production with SRV's from microseismic data falls on different frac spacing curves

Note how most wells plot at a fracture spacing greater than 200ft and many greater than 800ft

The greater the spacing the less effective the fracture in a given SRV



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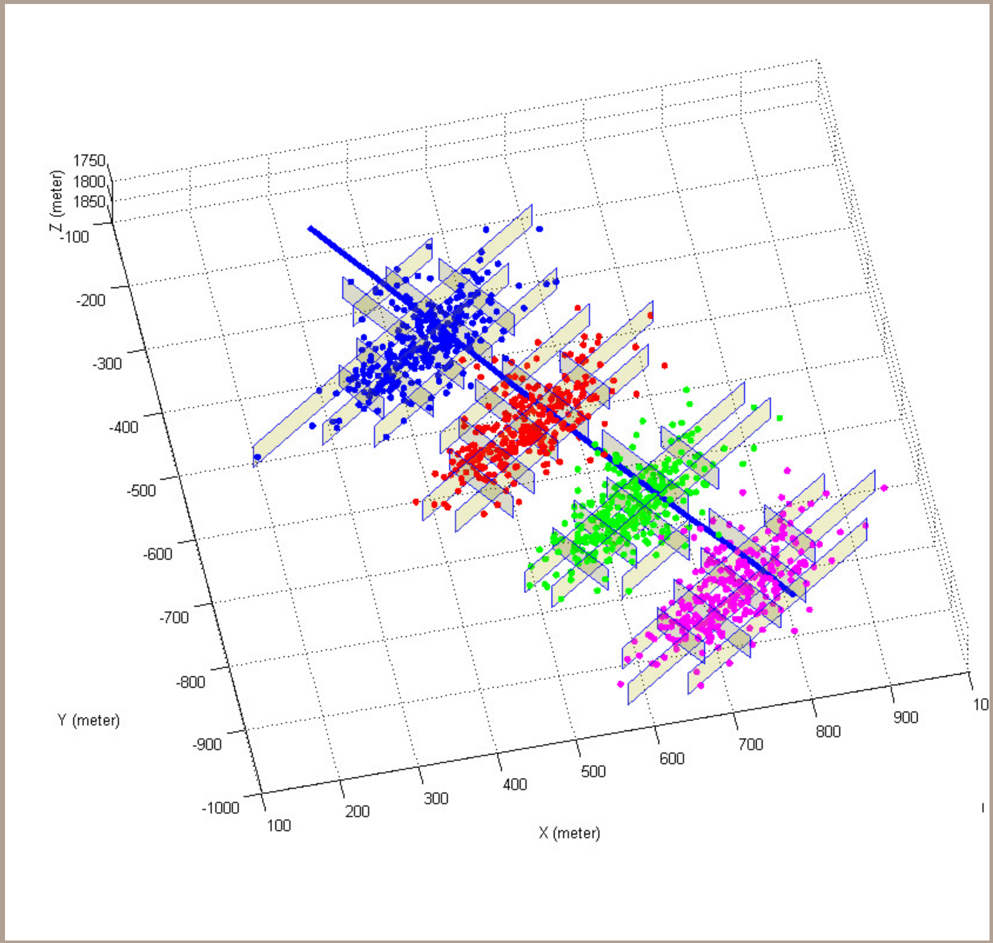
Fracture Planes from Microseismic Data for a “Complex” Fracture System



Proppant Transport Scenarios

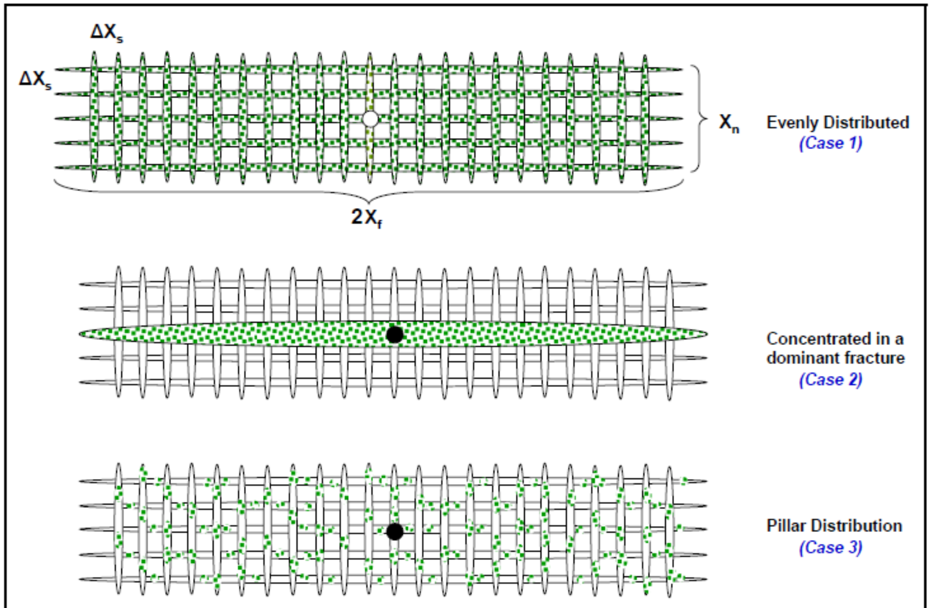


Figure 3 - Proppant transport scenarios (plan view)

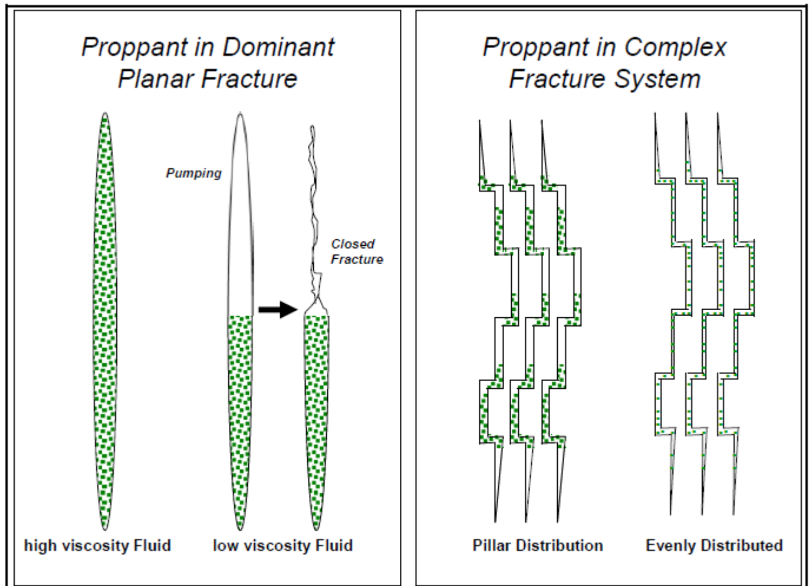


Figure 4 - Proppant transport scenarios (side view)

Possible ways to describe conductivity distributions within a fracture network and an example of how to change conductivity within a reservoir simulator

SPE115769

Why is it important to understand your rock when building the simulator?

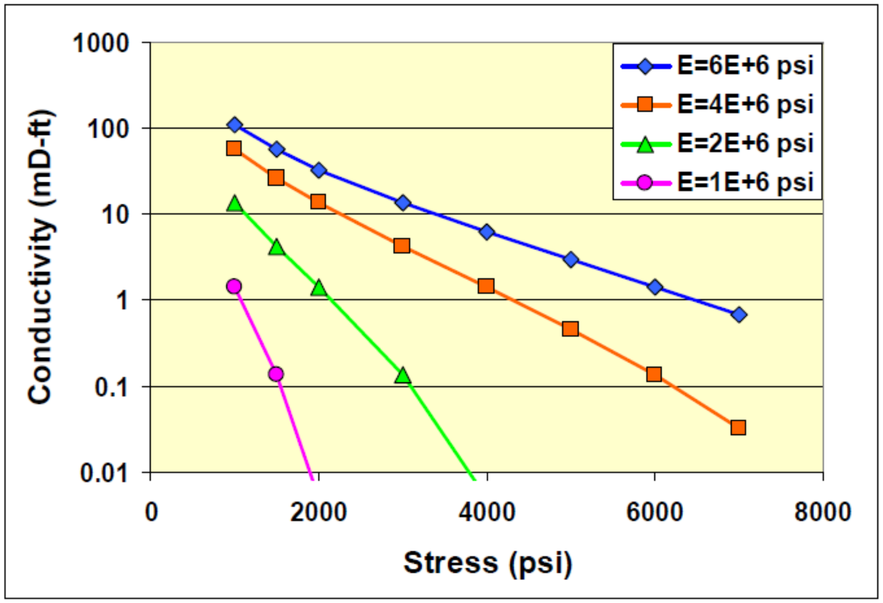


Figure 6 - Effect of modulus on conductivity of un-propped fractures with shear offset, extrapolation of Fredd data using Walsh model

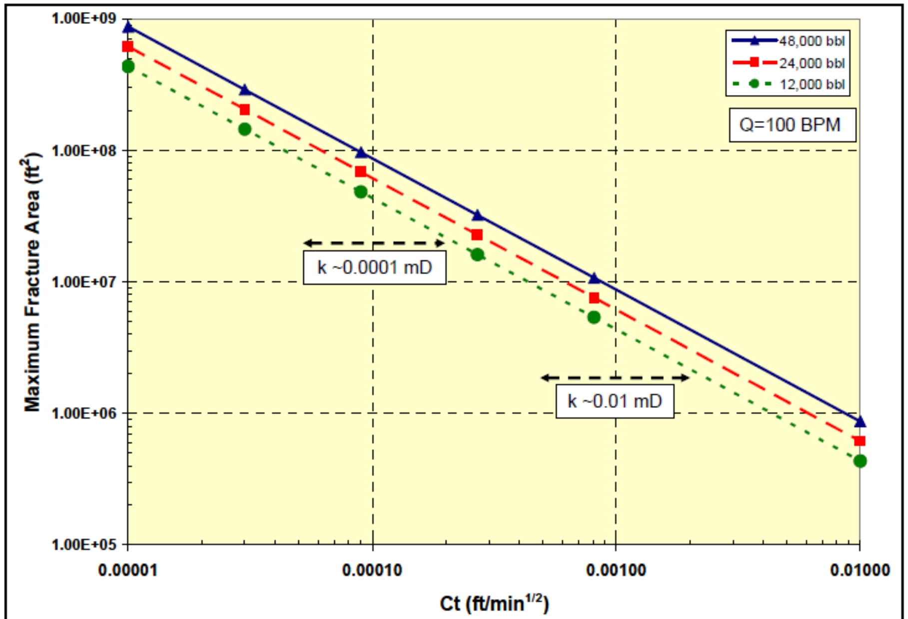


Figure 15 - Maximum fracture area as a function leakoff coefficient

Young's modulus effect on un-propped conductivty

- Based on Fredd's work (SPE Journal Sept 2001)

- Permeability is important to understand potential SRV that can be generated

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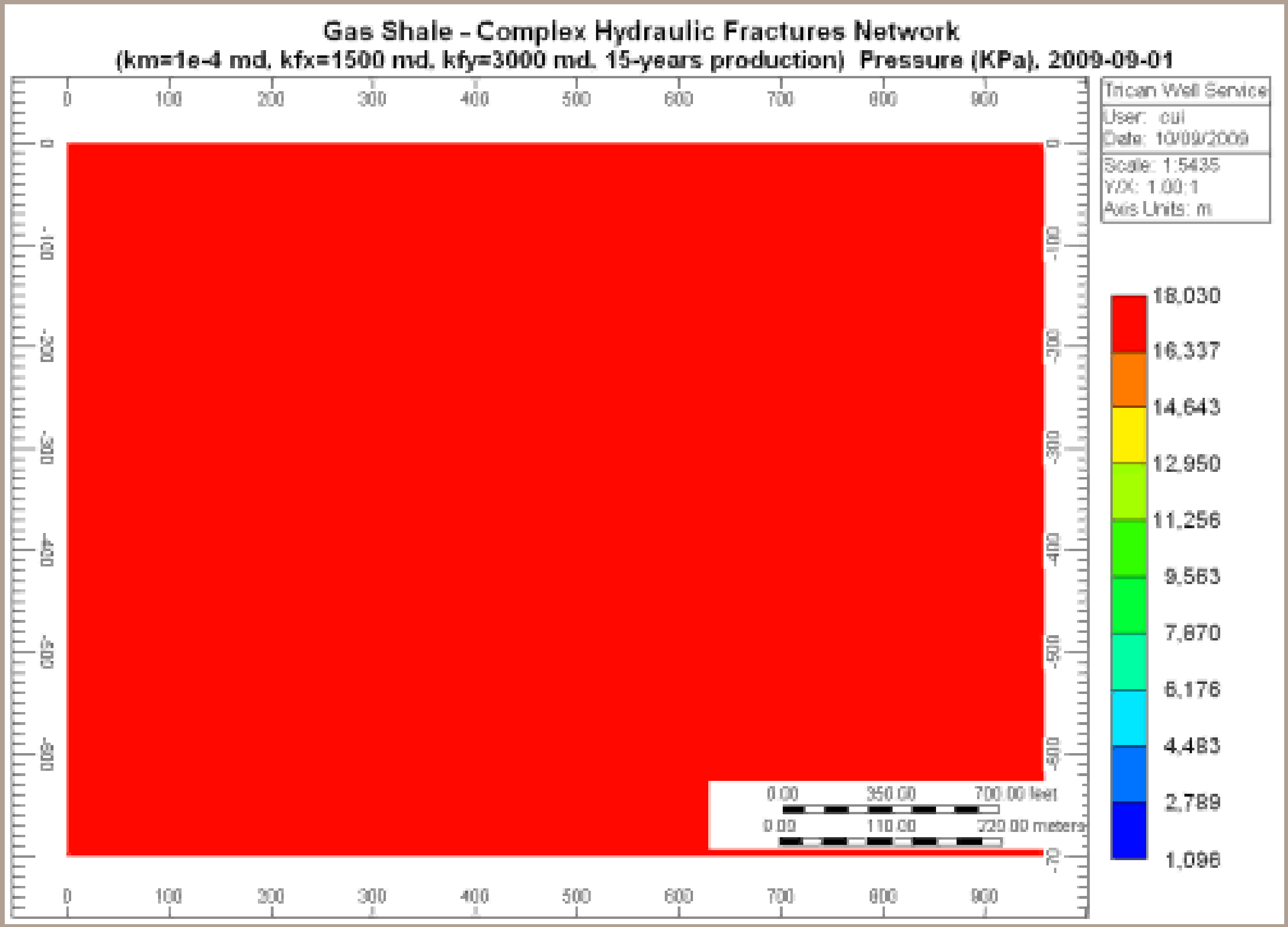
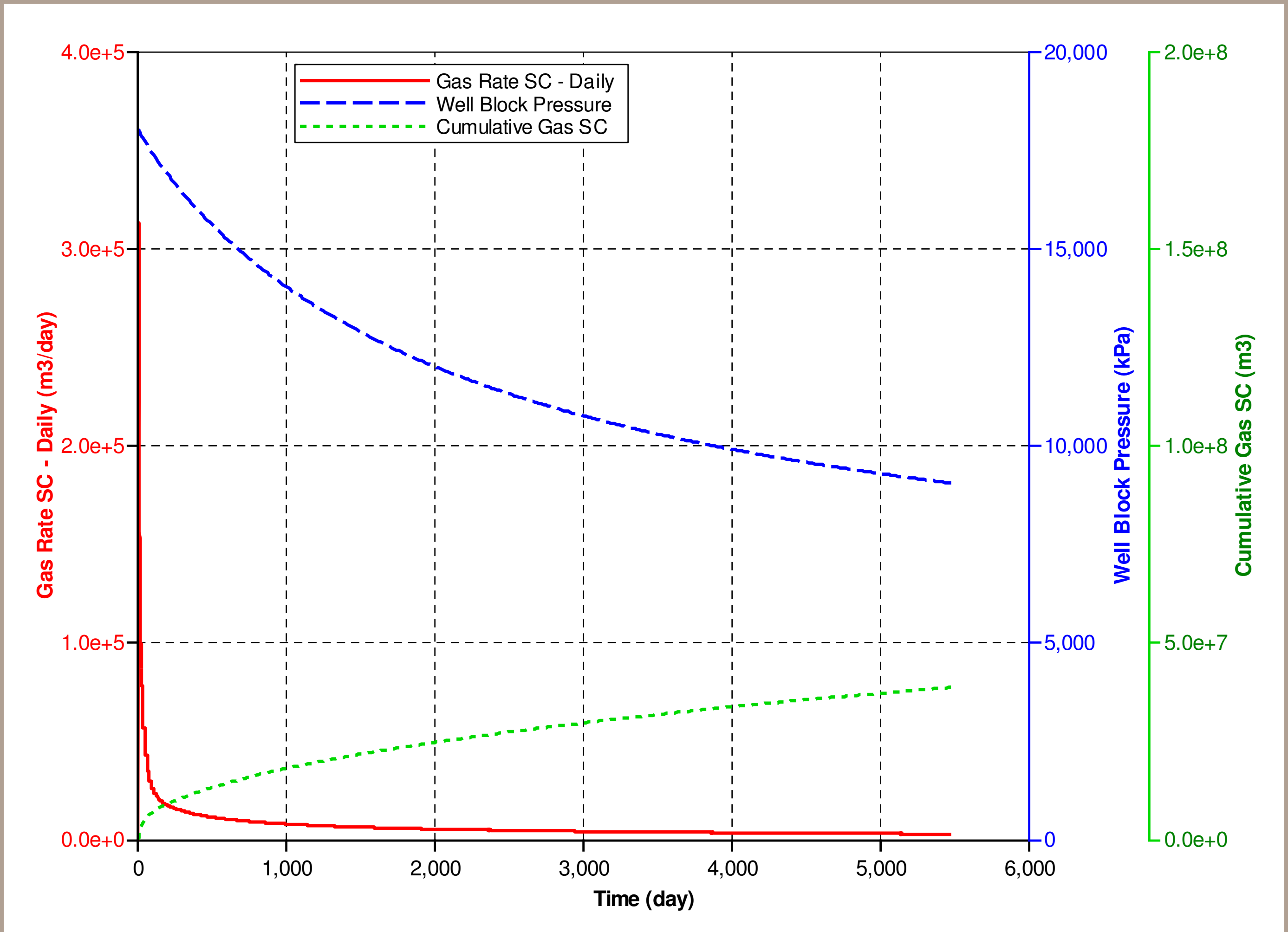
Production Surrounding Fracture Planes for a "Complex" Fracture System



Production from Reservoir Simulator for “Complex” Fracture System



- Production matching different conductivity distributions
- Does production make sense

Applying SRV and Network Azimuth to Well Placement and Spacing Strategies

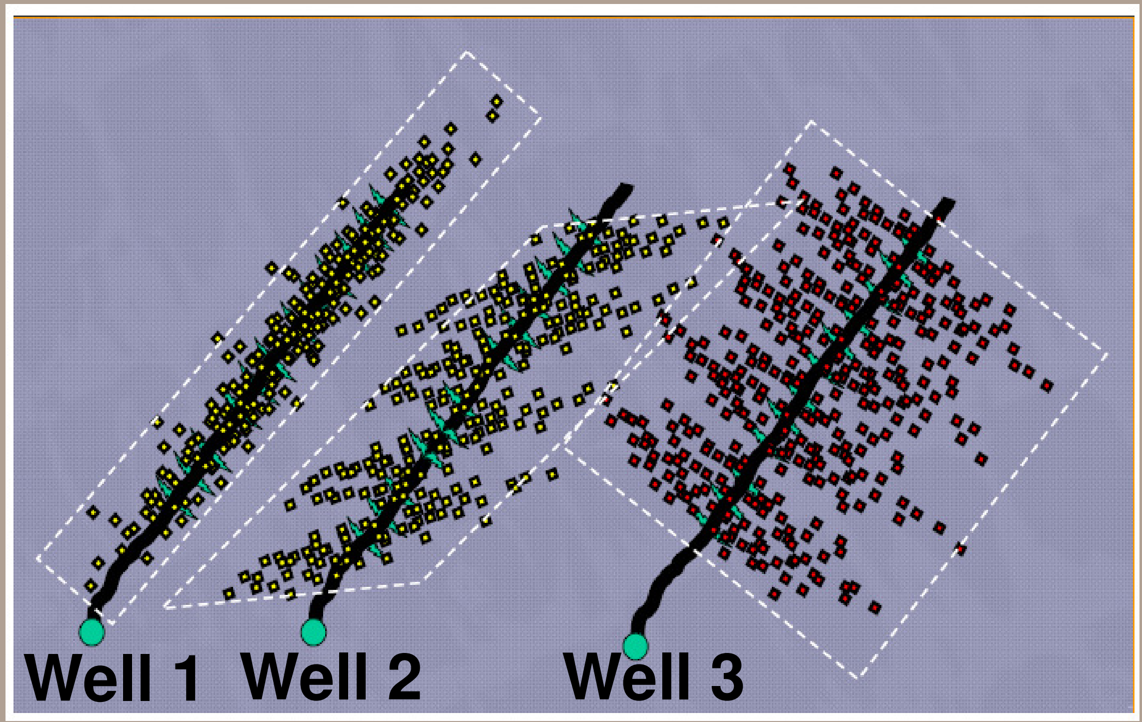


Figure from SPE119890

Well 1 – Longitudinal Frac; more wells with closer spacing needed

Well 2 – Inefficient reservoir drainage as fractures are not truly transverse to the wellbore

Well 3 – Largest SRV with transverse fractures

Applying SRV and Network Azimuth to Well Placement and Spacing Strategies

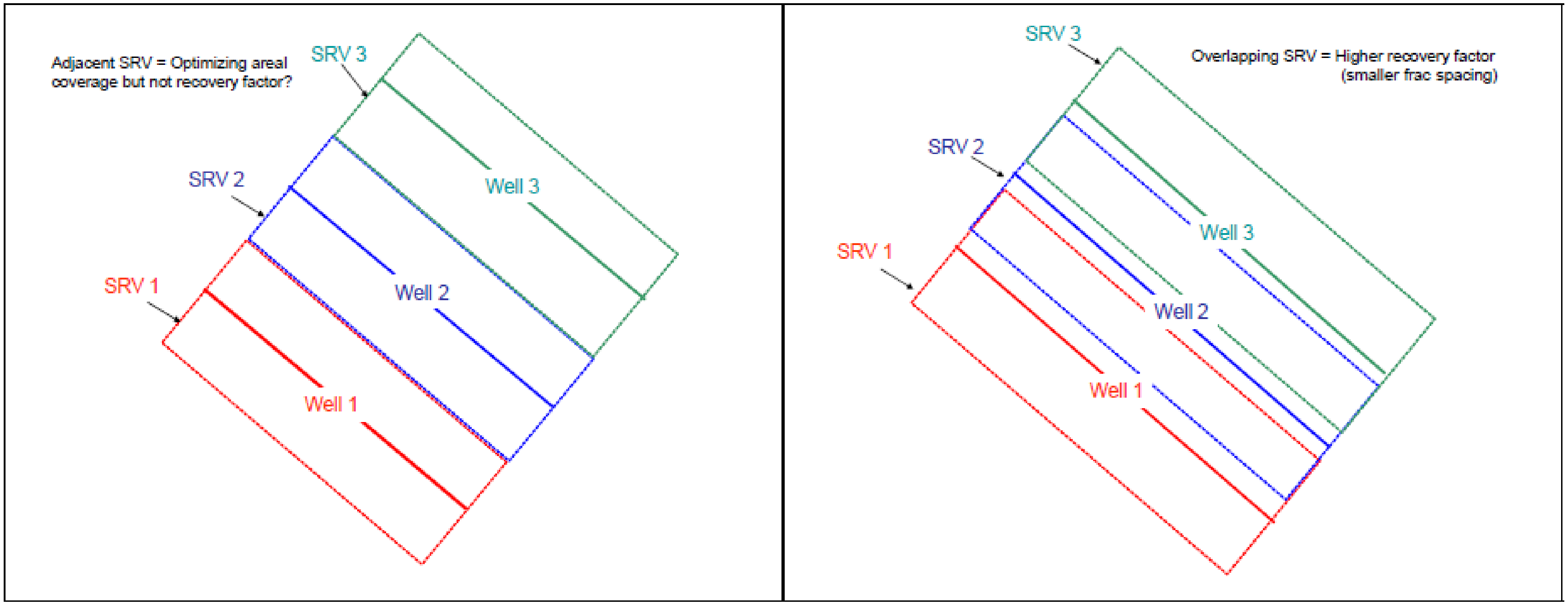


Figure from SPE119890

When optimizing well placement should SRV's for wells and stages overlap?

It has been shown that more closely spaced fracs in the SRV is beneficial, so more closely spaced stages and well will increase gas recovery within the SRV

Conclusions

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Low permeability reservoirs require large SRVs with small fracture spacing and adequate frac conductivity

Important to understand parameters in the reservoir that will create complexity so fracture spacing in the SRV can be understood

Engineering measures to increase SRV and frac spacing

- Length and orientation of horizontal well
- Treatment size
- Number of stages, number of perf clusters
- More stages and clusters in a cased/cemented completion increased likelihood of dense fracturing
- Zipper fracs, Simul-fracs

Conclusions

Integration of information sources is important to better understand a shale gas reservoir

- Core Work
- Microseismic
- Fracture Modelling
- Log Information

These inputs can be used in a reservoir simulator to better understand the reservoir and production from it