# Understanding Organic Shale

## Reservoir Quality & Completion Quality




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European Unconventional, Schlumberger

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# Understanding Organic Shales - Outline

- European Shale today
- What are organic shales?
- What makes them Unique?
  - » Reservoir Quality
- What makes them Produce?
  - » Completion Quality
- How do you make a shale project economic?

# European Shale Gas Today – after 3 years

## Countries that have drilled Shale Gas Wells

- Poland – 34 Vertical / 5 Horizontal
- Turkey – 6 Vertical / 1 Horizontal
- Germany – 3 Vertical
- Bulgaria – 1 Vertical
- Sweden – 3 Vertical
- UK – 3 Vertical

## Countries that have Completed & Tested

- Poland – 7 Vertical / 3 Horizontal
- Turkey – 2 Vertical / 1 Horizontal
- Germany -1 Vertical
- UK – 1 Vertical

## Countries with measured production

- Poland – 1 Horizontal Well
- Turkey – Comingled Production

***We are still in the Exploration Phase!!***

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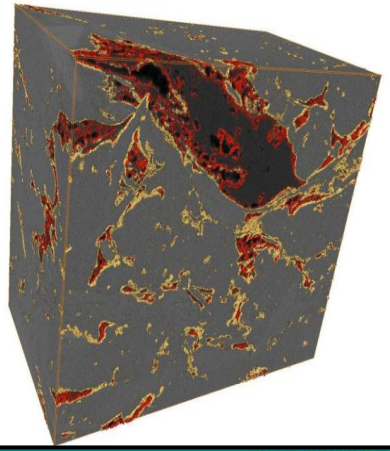
# What is an Organic Shale ?

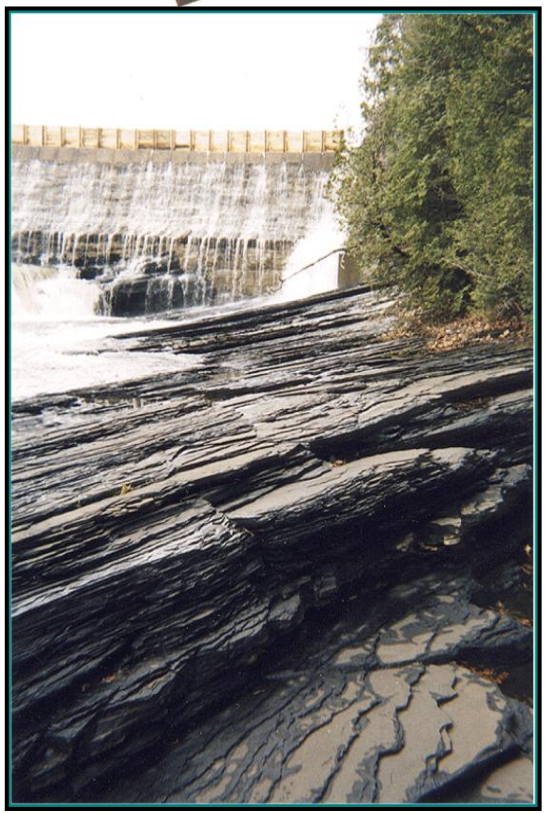
## Not a typical shale, but a unique rock type

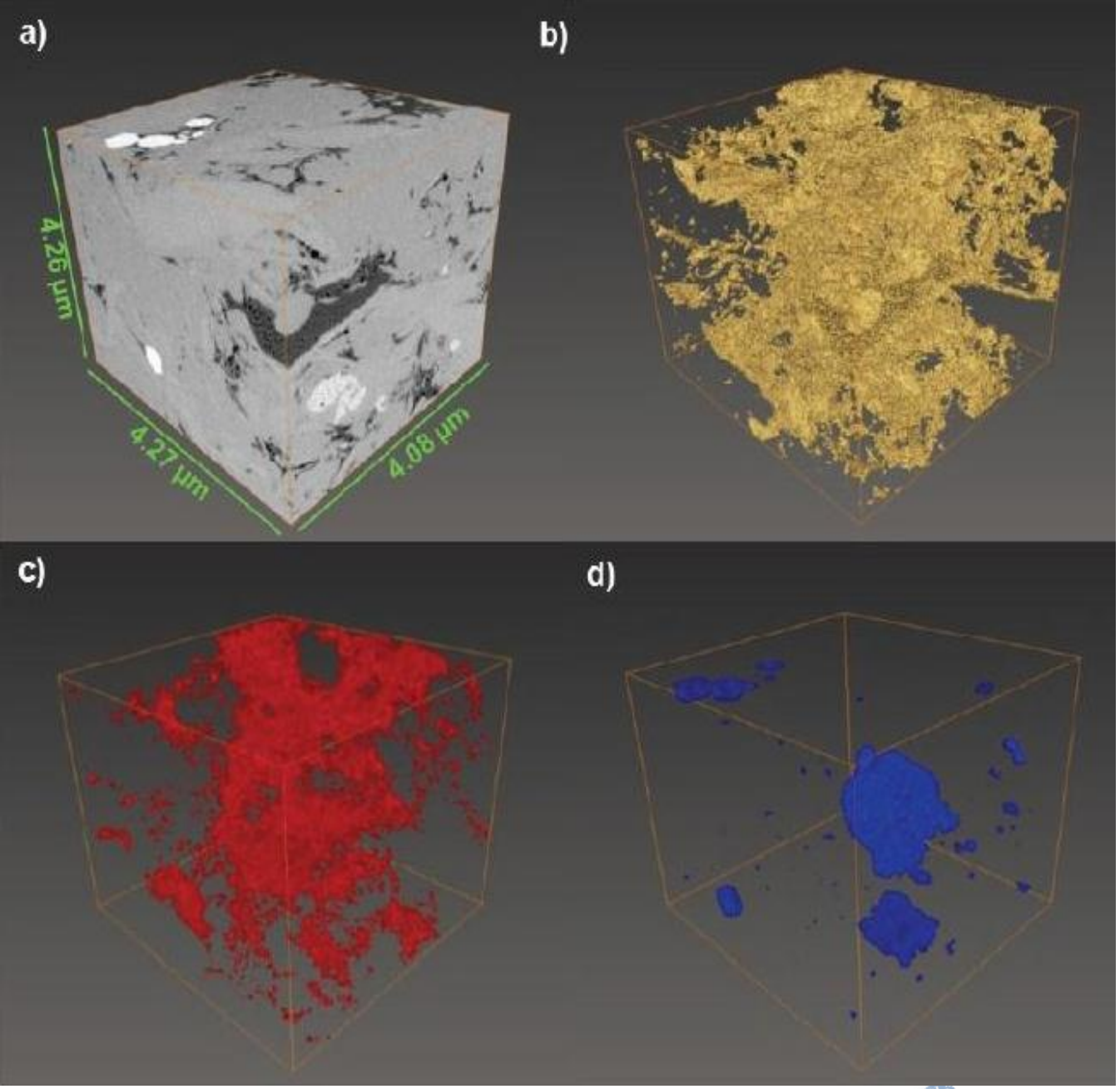
- Deposited in environment with little or no oxygen
- Scavengers can't survive and dead organisms accumulate.
- If organic matter > 5%, sediment forms "Black Shale"

# Organic Shale Reservoirs



- Organic Rich Shale
- Source Rocks
- Surrounding poor quality rock ignored as non-economic in the past.
- Porosity sources are mostly unconventional
- Matrix rock has very low permeability
- Require hydraulic stimulation to make productive






# Organic Shale Reservoirs

a) 3d solid matrix

b) Kerogen volume

c) Pores

d) Pyrite

SPE 137693



# Exploration Challenge – Goals of Shale Evaluation

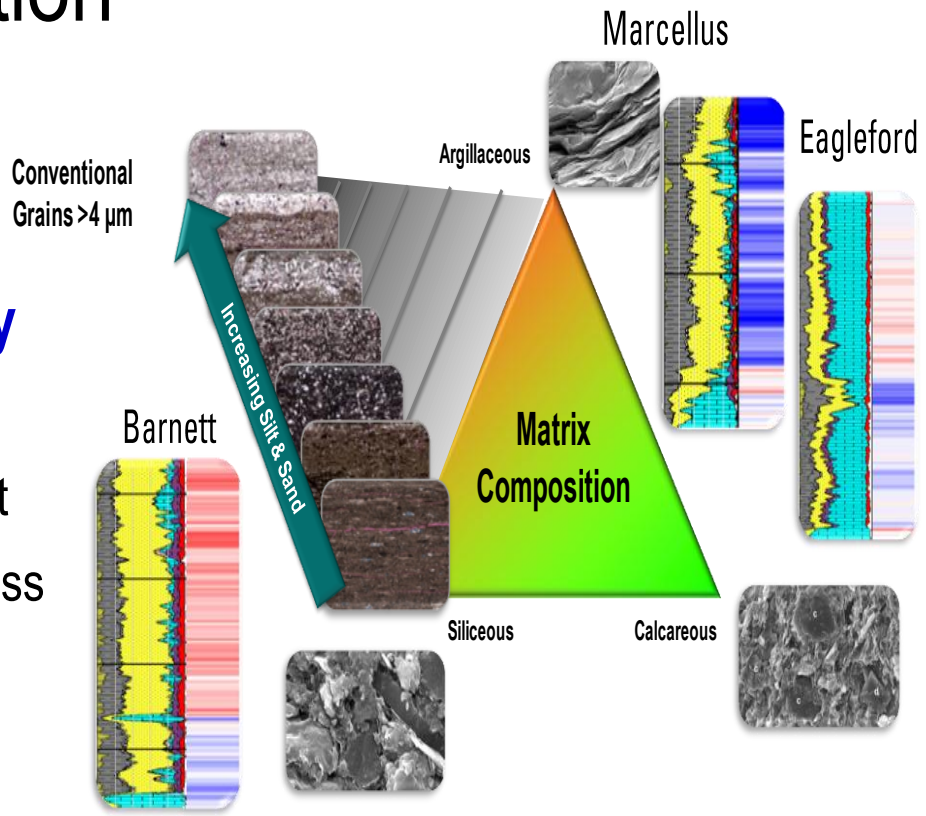
## Reservoir Quality

- Maturity
- Organic content
- Clay Content & volume
- Porosity
- Permeability
- Water saturation
- Pressure
- Gas in place

## Integration

## Completion Quality

- Stress anisotropy
- Fracture containment
- Near & Far Field stress
- Clay content & type
- Fabric pattern
- Wellbore placement
- Chem-Mechanical weathering

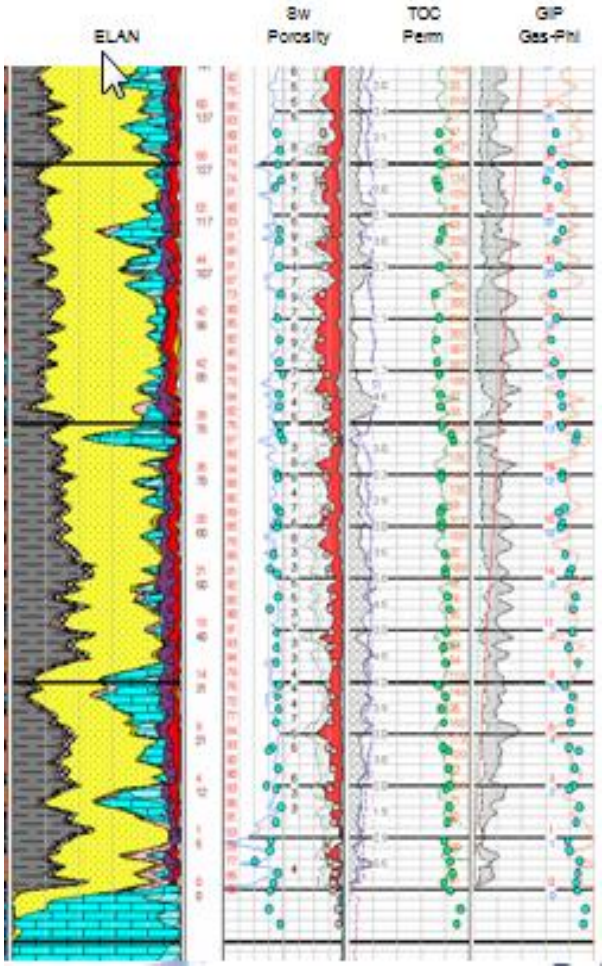





# Reservoir Quality– How to Evaluate Shale

## Reservoir Quality

| | |
|---|---|
| Maturity | Confirmed from Core |
| Organic content | Core Measured Volume & Type |
| Clay content & type | Clay Volumes and Type |
| Porosity | Type & Relationship to Kerogen Wettability |
| Permeability | Core Measure Perm. |
| Saturation | Saturation from retort analysis |
| Pressure | Estimate from fall off test |
| Gas in place | Free and Absorbed Gas Desorption Reference |




→ **Integrated Shale Evaluation, Calibrated GeoChemical Model**

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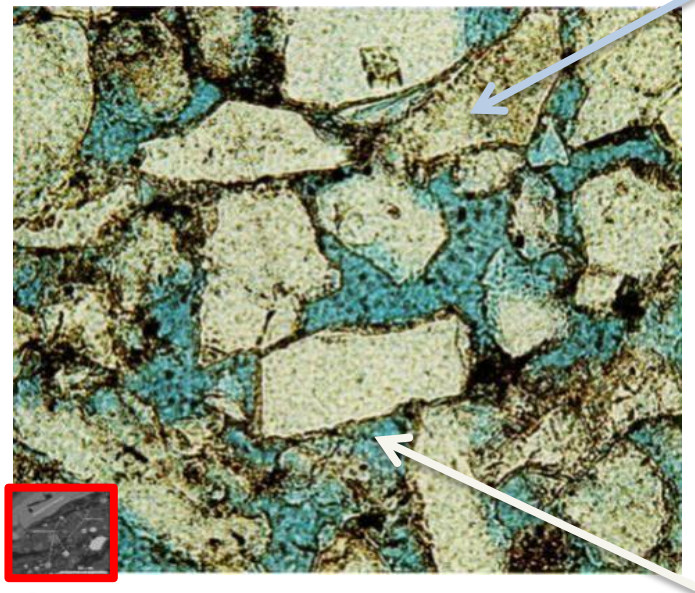
# Shale Reservoir Quality – Organic Content & Porosity

Conventional sandstone



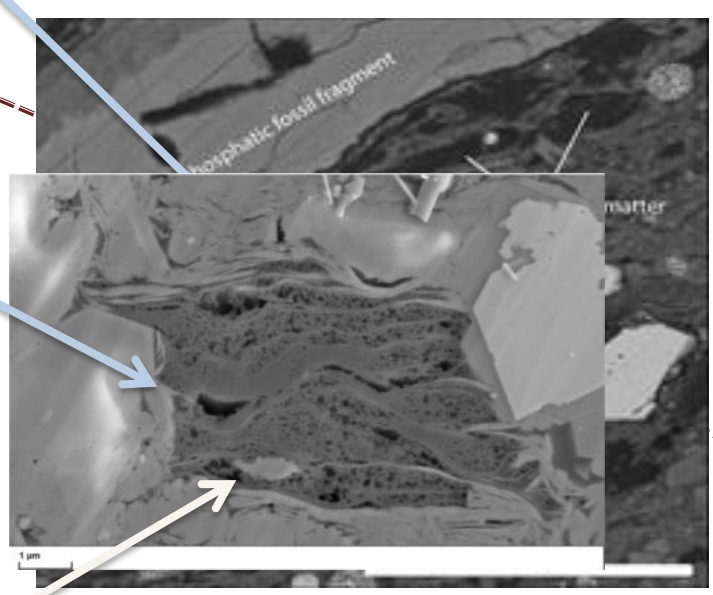
700 μm
Free gas in pore space

Mineral framework

Kerogen

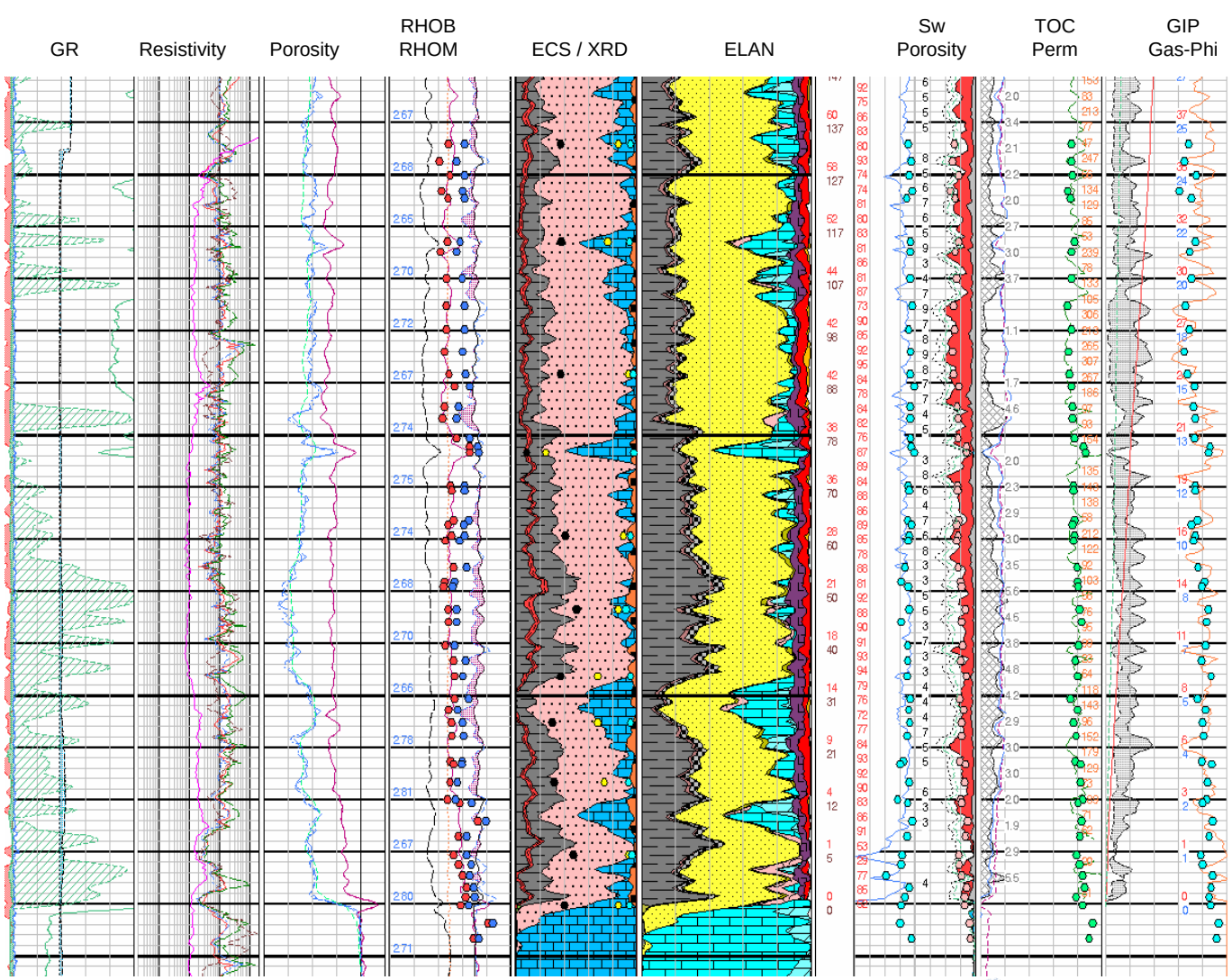
Pore system

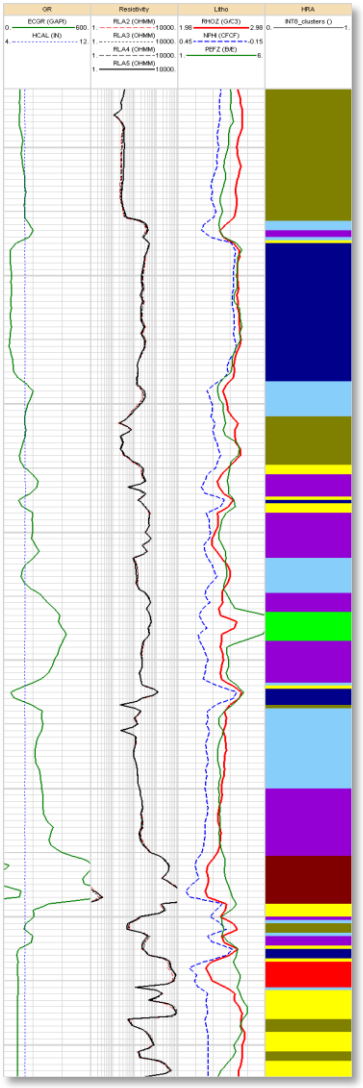
Gas shale



100 μm
Free gas in pore space
Adsorbed gas on kerogen

# Reservoir QualityGeoChemical Shale Model / HRA



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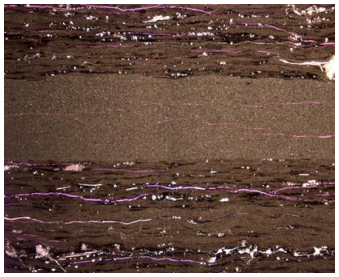
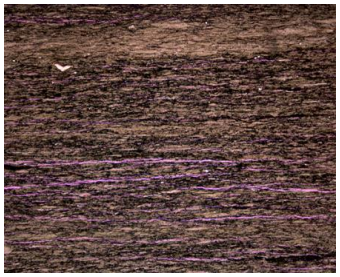
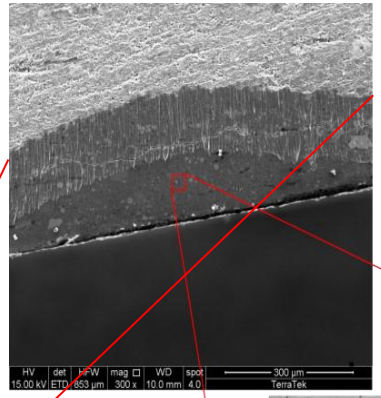
# Reservoir Quality – Core Evaluation (TRA)

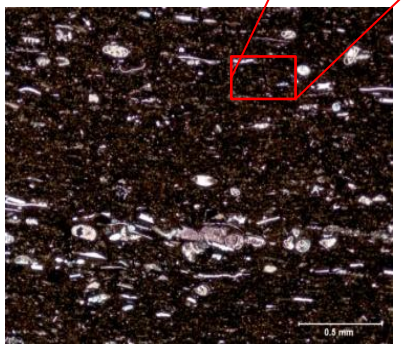
- Measurements made on crushed rock particles
- Crushing dramatically increases the surface area of the sample
- Removes the artifacts induced when retrieving core
- The pore system is preserved
- Each particle contains thousands of pores
- Crushed sample particles are representative

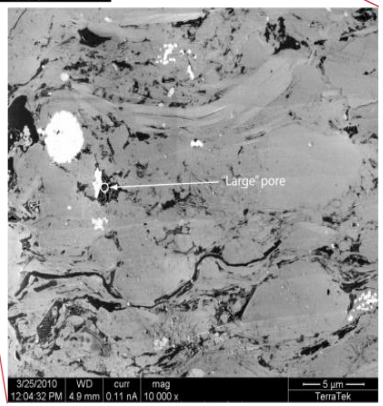




Cascading view of pore size versus particle size shows how small the pores really are

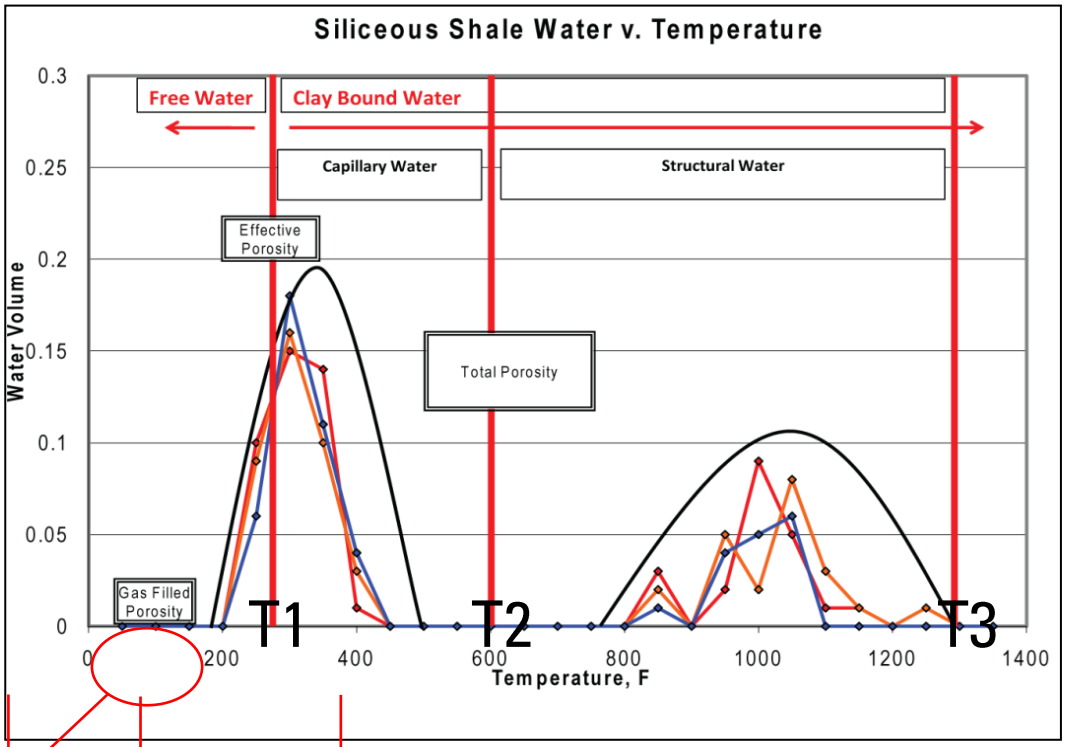




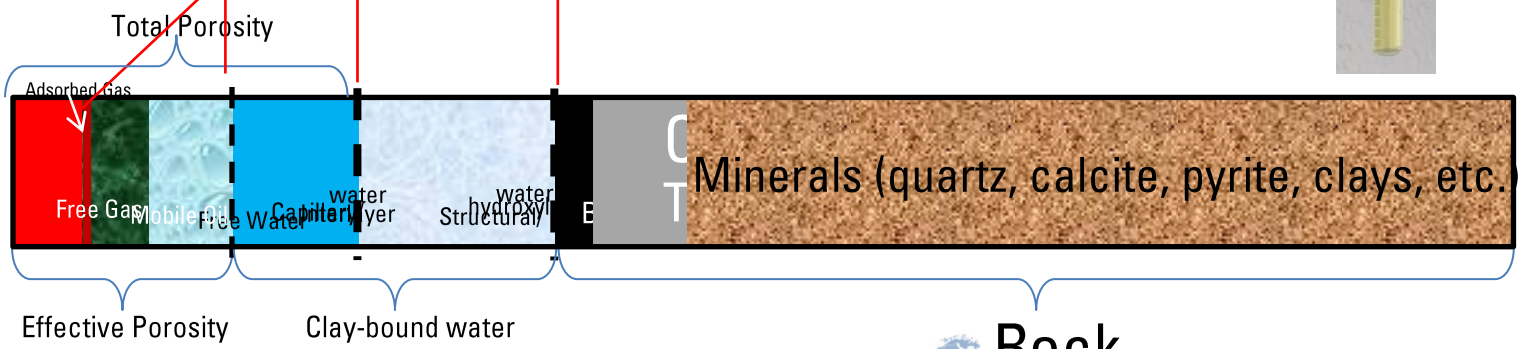





# Reservoir Quality – Retort Saturation Analysis







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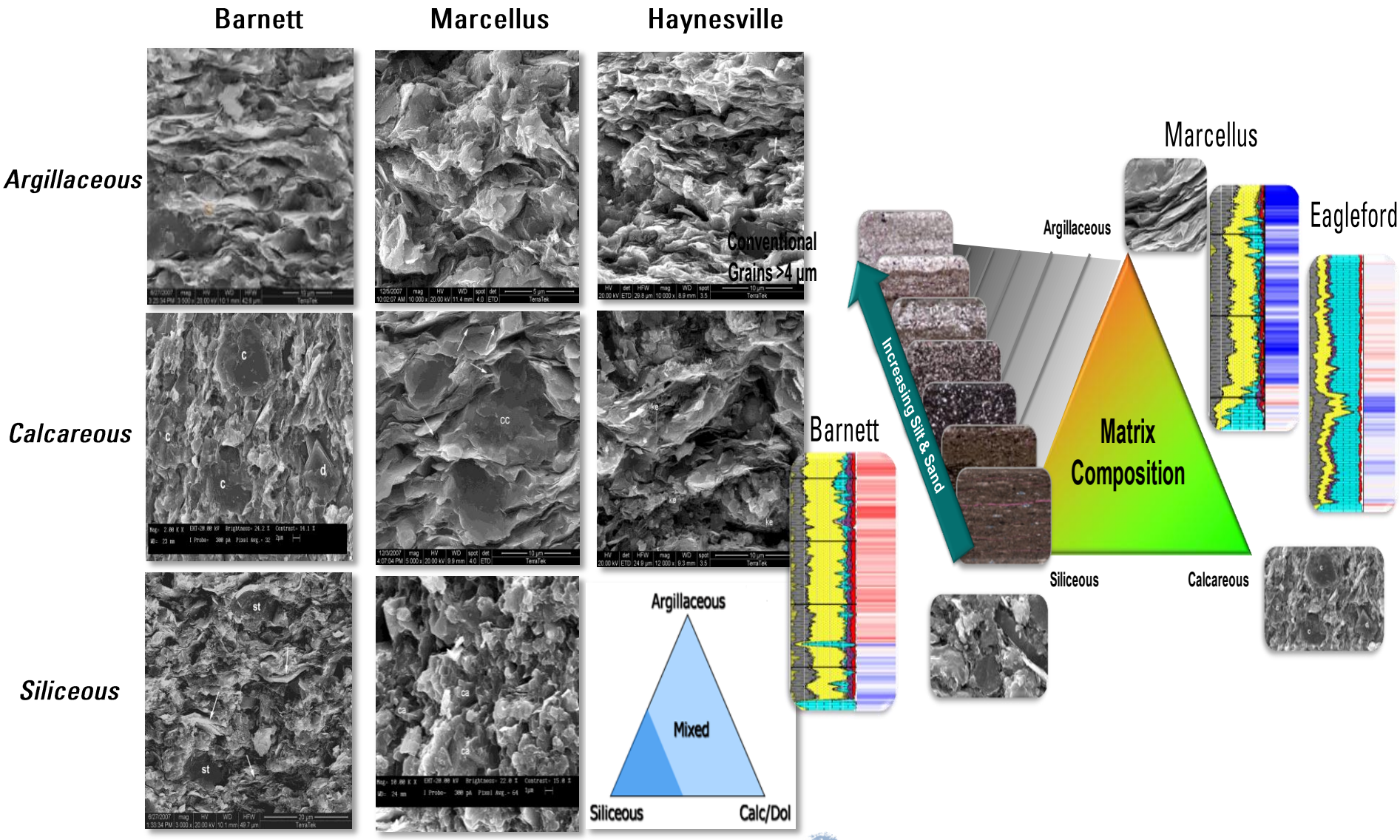
# Reservoir Quality - Maturity Control – Petrology



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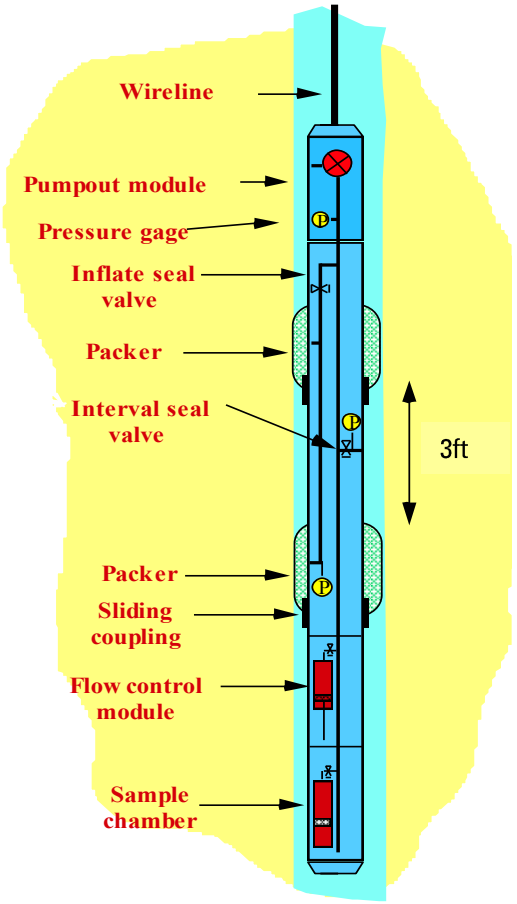
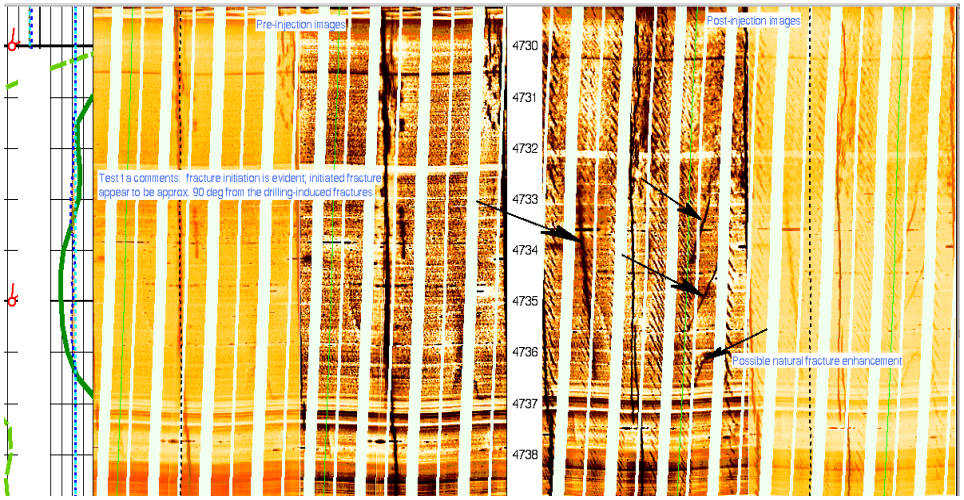
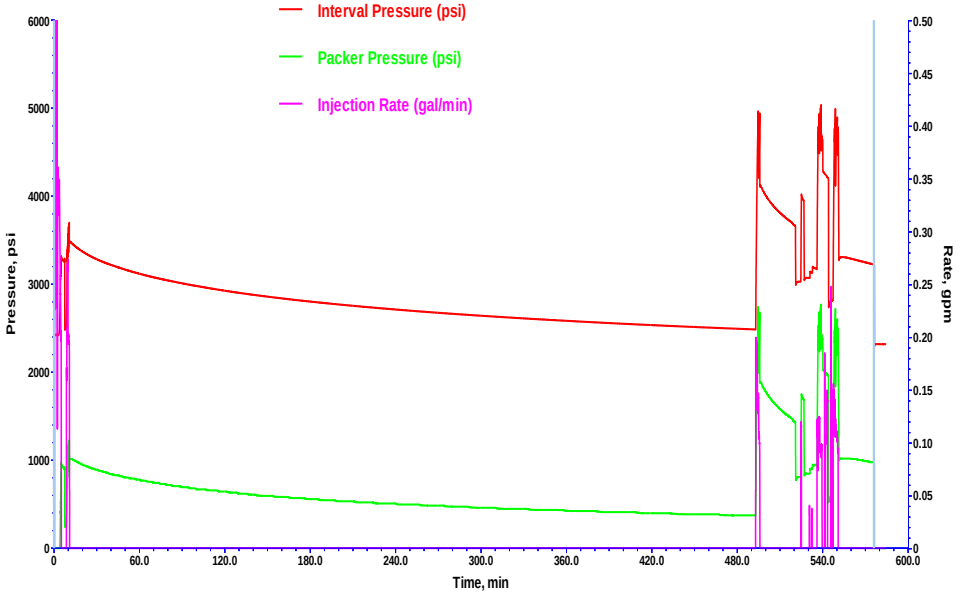
# Reservoir Quality – Pressure Measurement



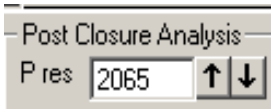



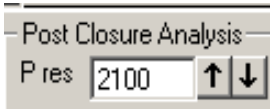



# Reservoir Quality – Pressure Measurement

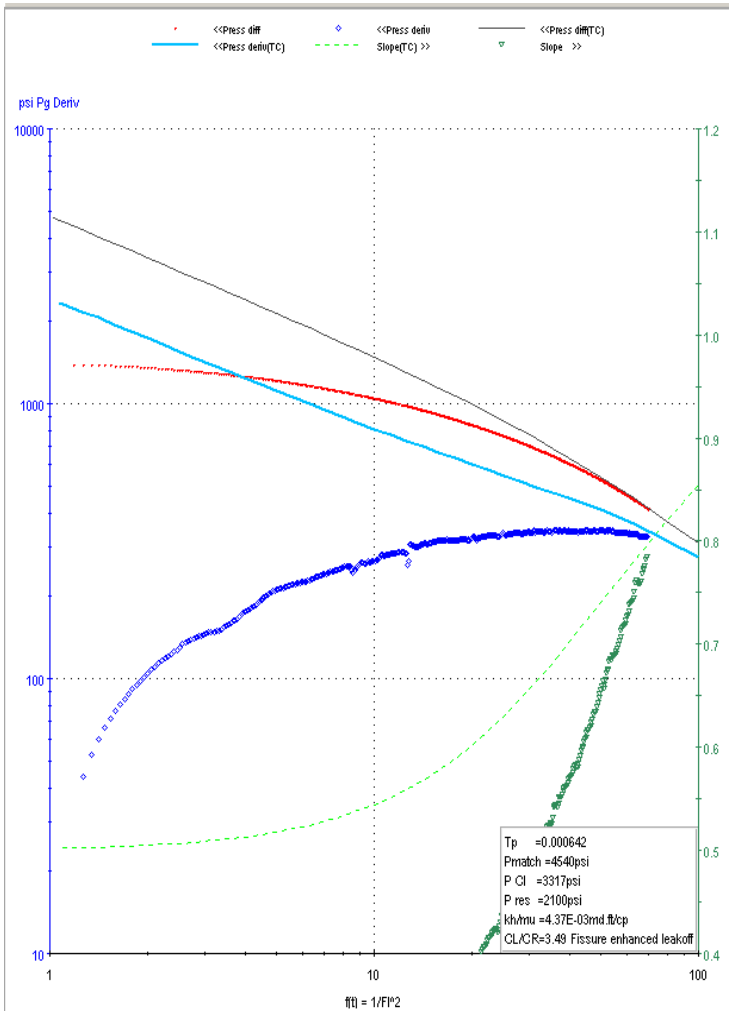
Eight Hour Shut-in




35 psi




- Run Sensitivity during Closure
- Estimate pressure at 0.453 psi/ft
- Gradient used to estimate Gas in Place, assuming Saturated System



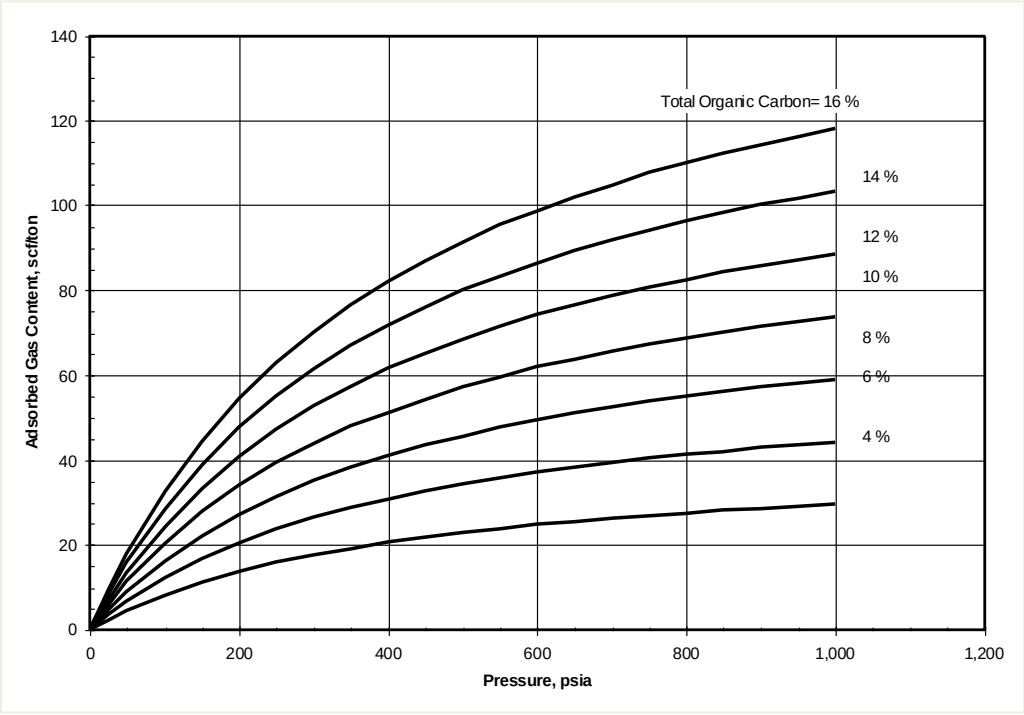



# Reservoir Quality – Gas in Place

- Gas in Place Calculated from CBM Standard BCF per Sq Mile
- TOC is considered Saturated for most cases as most wells are over 1000 psi
- Effective porosity is used with estimated pore pressure.
- Gas in Place is Integrated over total Shale bottom to top of interval.
- Examples:
- Core Barnett 139 BCF/ Sq Mile
- Marcellus 60 BCF/Sq Mile
- Haynesville 129 BCF/Sq Mile

## Methane Adsorption Isotherms

(as a function of Total Organic Carbon)



# Exploration Challenge – Goals of Shale Evaluation

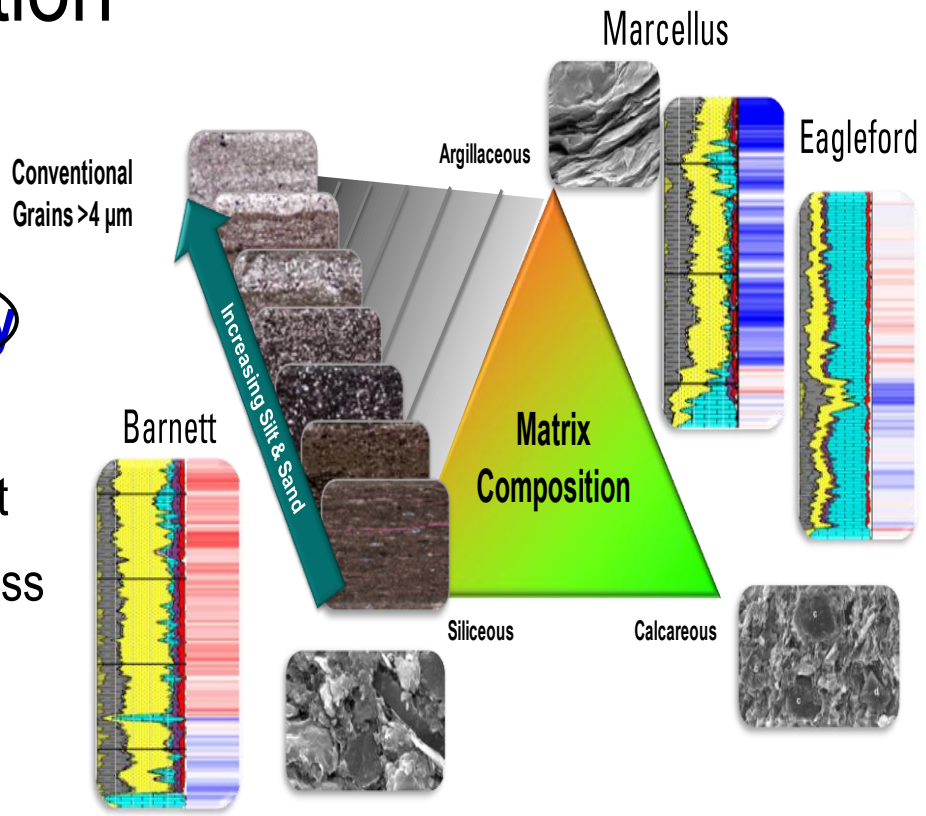
## Reservoir Quality

- Maturity
- Organic content
- Clay Content & volume
- Porosity
- Permeability
- Water saturation
- Pressure
- Gas in place

## Integration

## Completion Quality

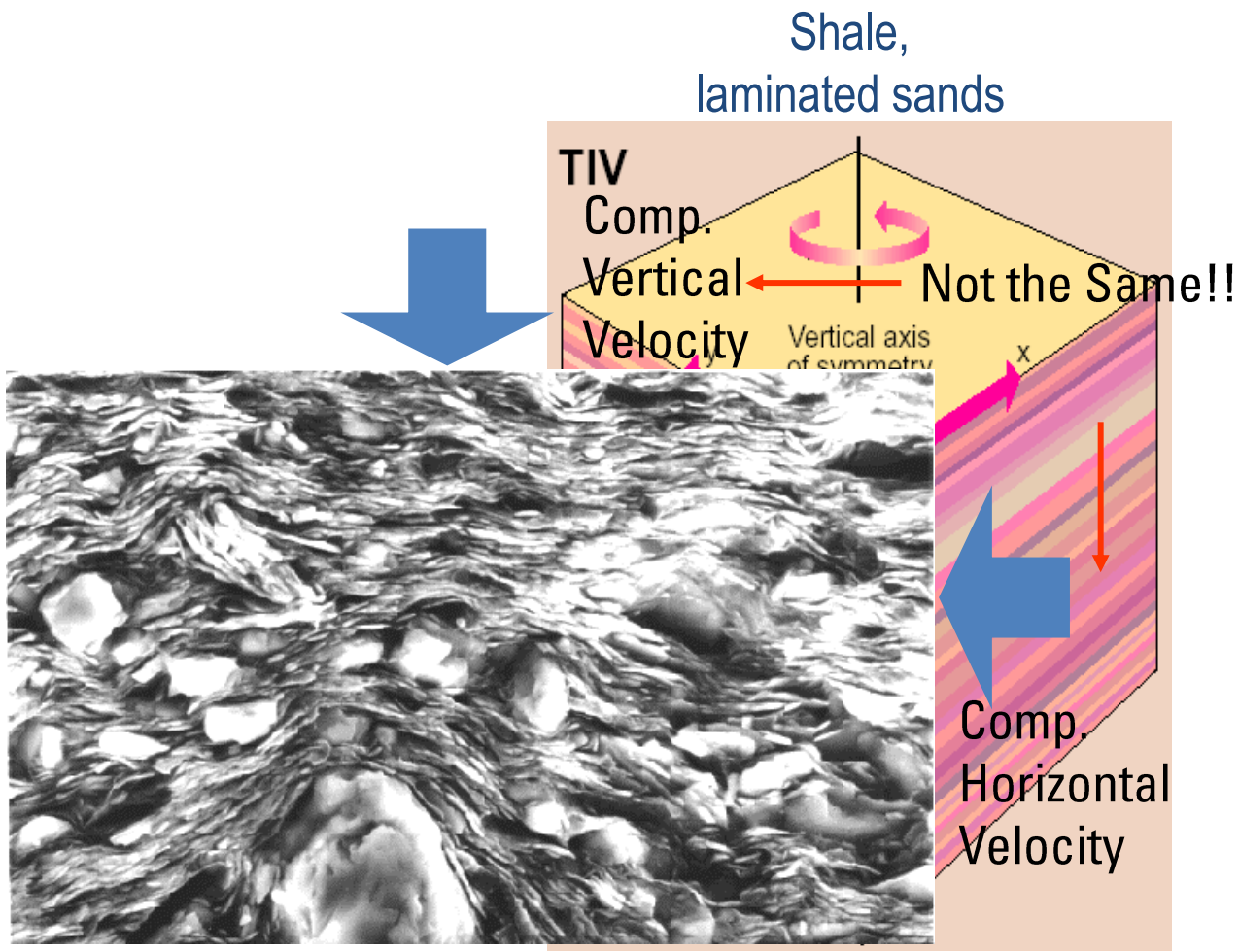
- Stress anisotropy
- Fracture containment
- Near & Far Field stress
- Clay content & type
- Fabric pattern
- Wellbore placement
- Chem-Mechanical weathering



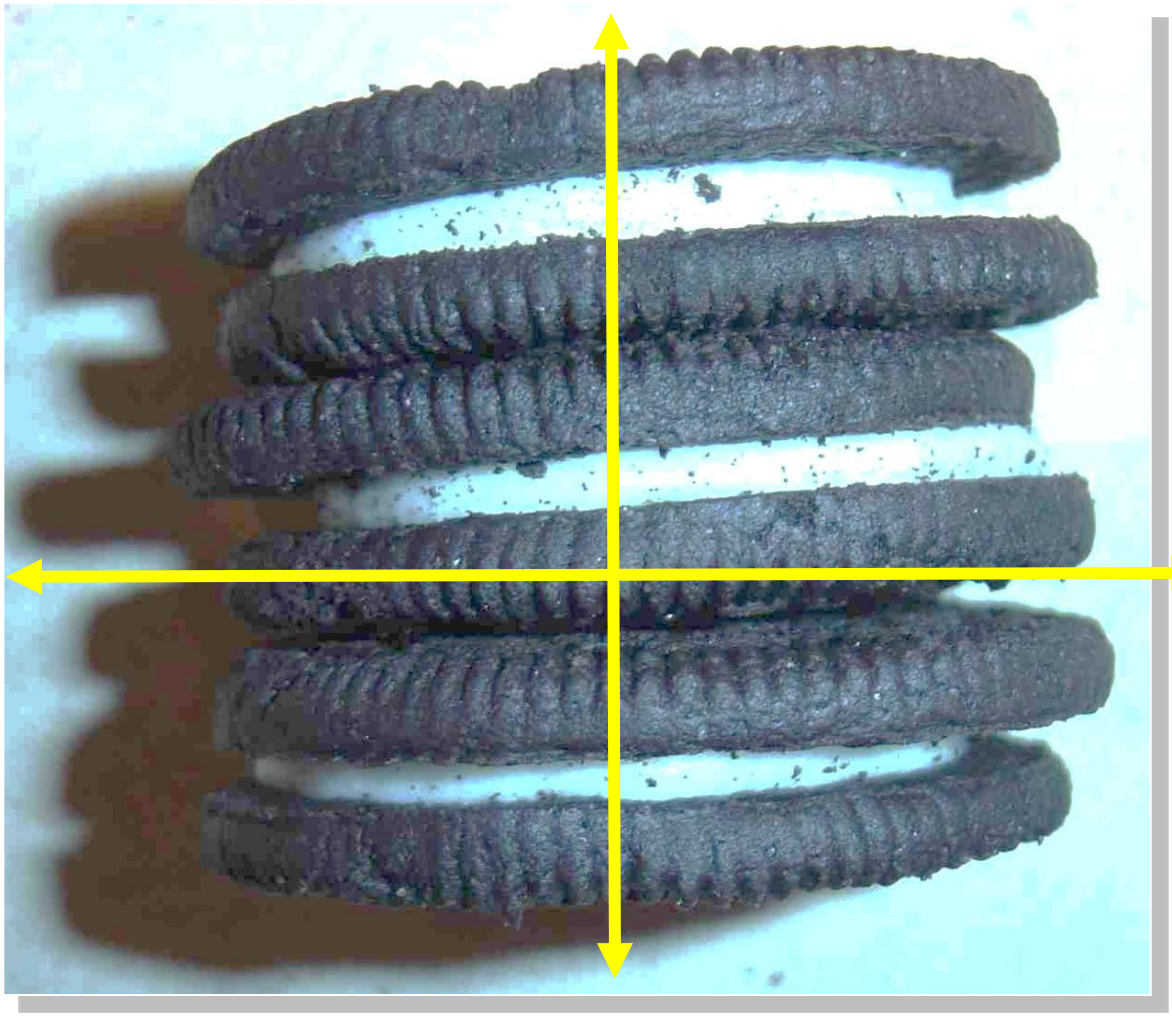
# Completion Quality – Anisotropic Properties

Shale can be very anisotropic due to laminations and bedding
(especially expandable clays and organics)

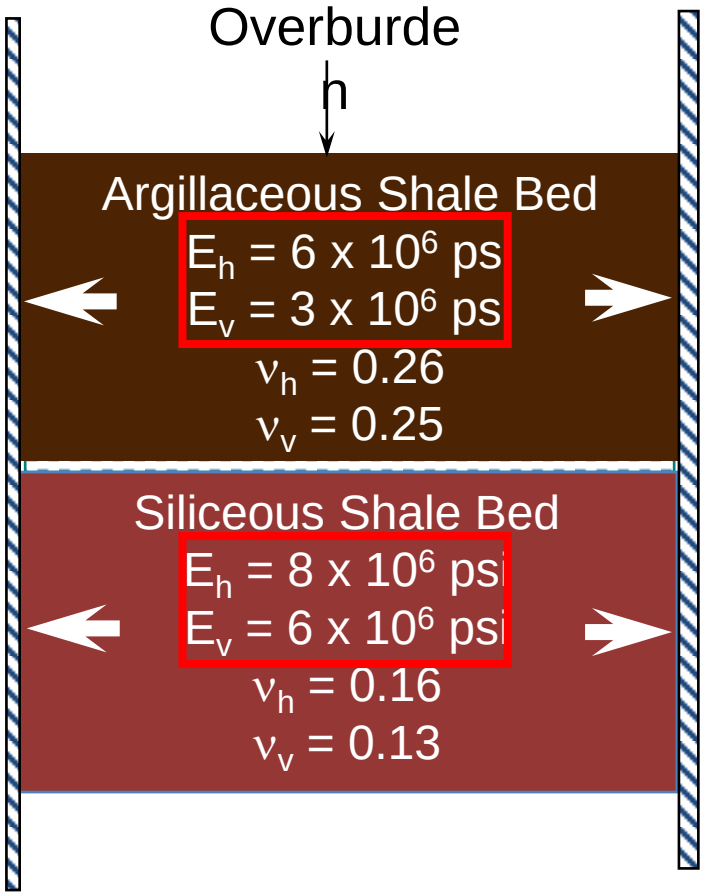
TIV = Transverse Isotropic with Vertical axis of symmetry



# Completion Quality – Anisotropic Properties



# Completion Quality – Anisotropic Stress




Argillaceous Shale:

Isotropic: $\sigma_h$ = 0.66 psi/ft

Anisotropic $\sigma_h$ = 0.87 psi/ft

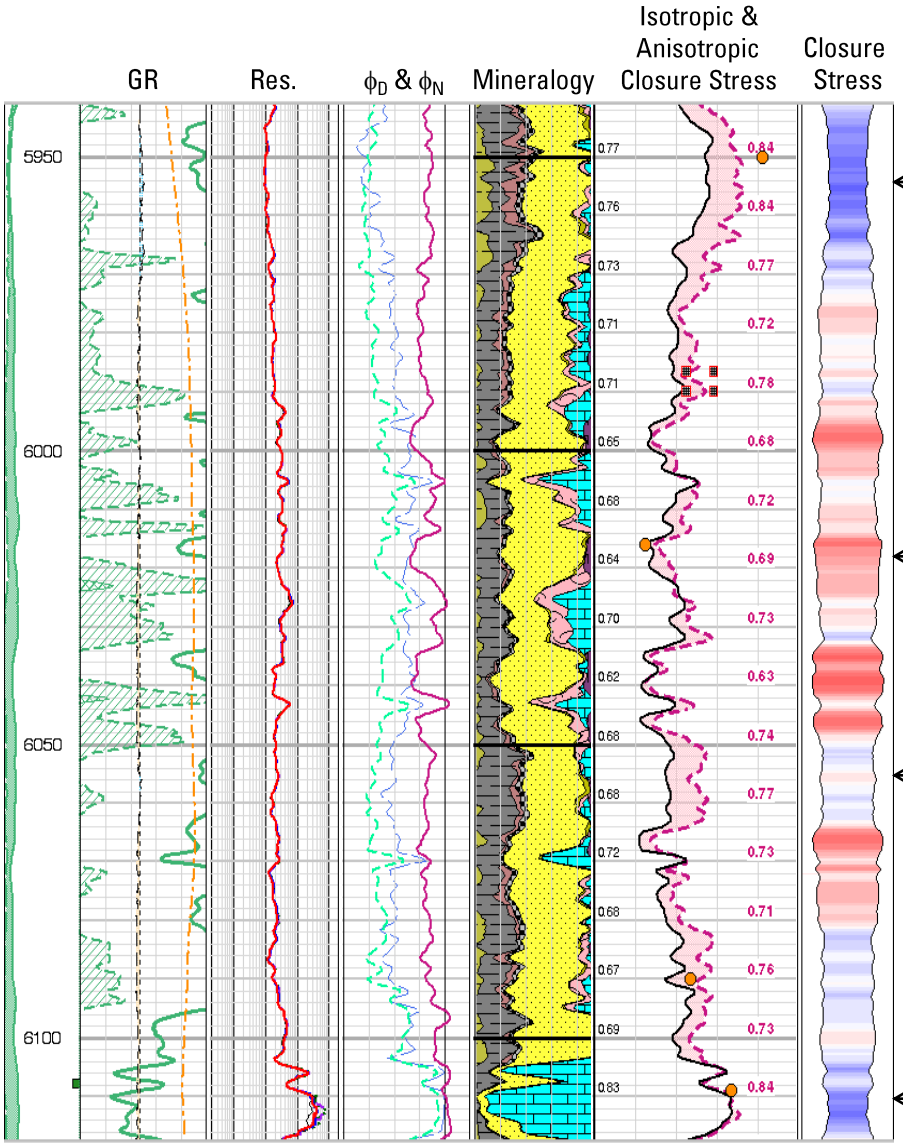
Siliceous Shale:

Isotropic: $\sigma_h$ = 0.53 psi/ft

Anisotropic: $\sigma_h$ = 0.57 psi/ft

***Anisotropic shale properties increases stress in argillaceous intervals***

# Completion Quality – Fracture Containment




← Swelling Clays = High Closure

Blue = High Closure Stress

Red = Low Closure Stress

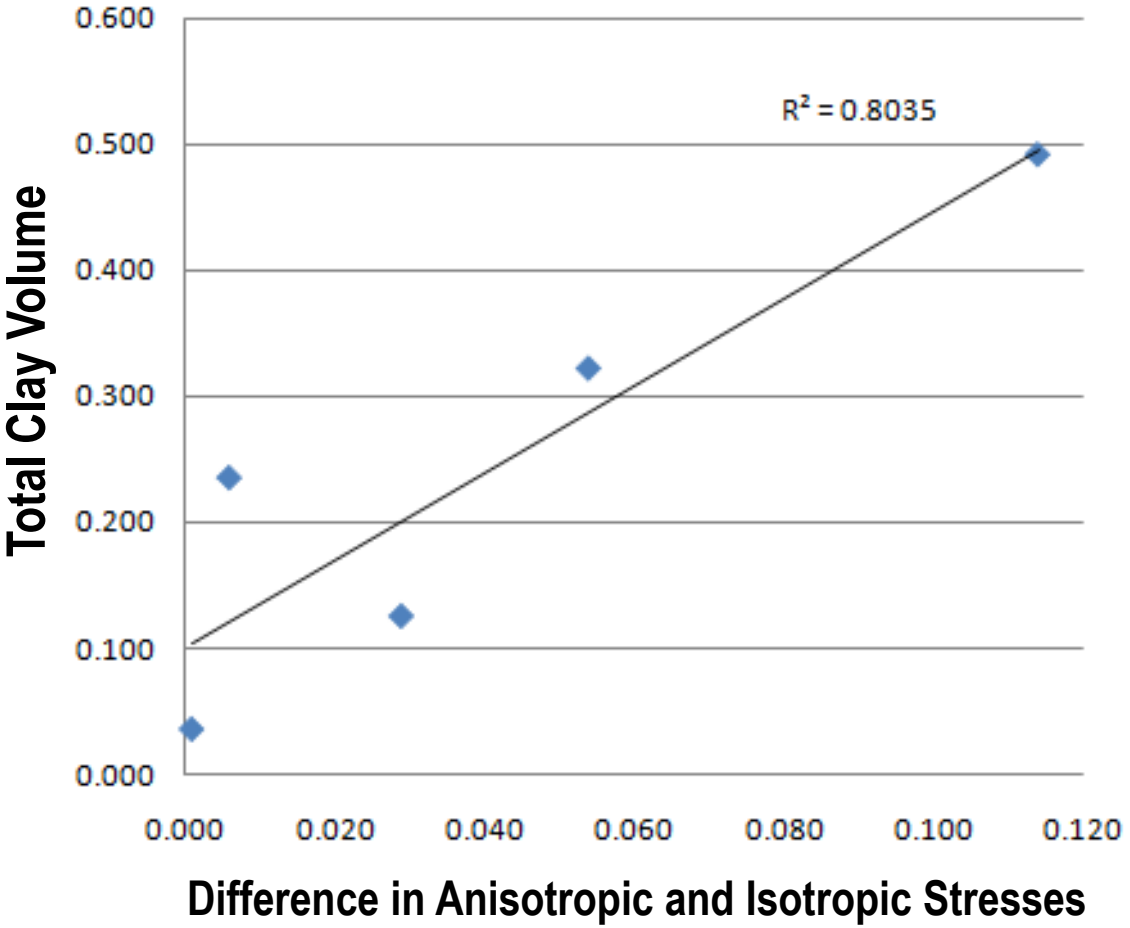
← High Silica Volume = Low Closure Stress

← High Clay Volume = High Closure Stress

← Carbonates: High or Low Closure Stress



# Completion Quality – Clay Volume



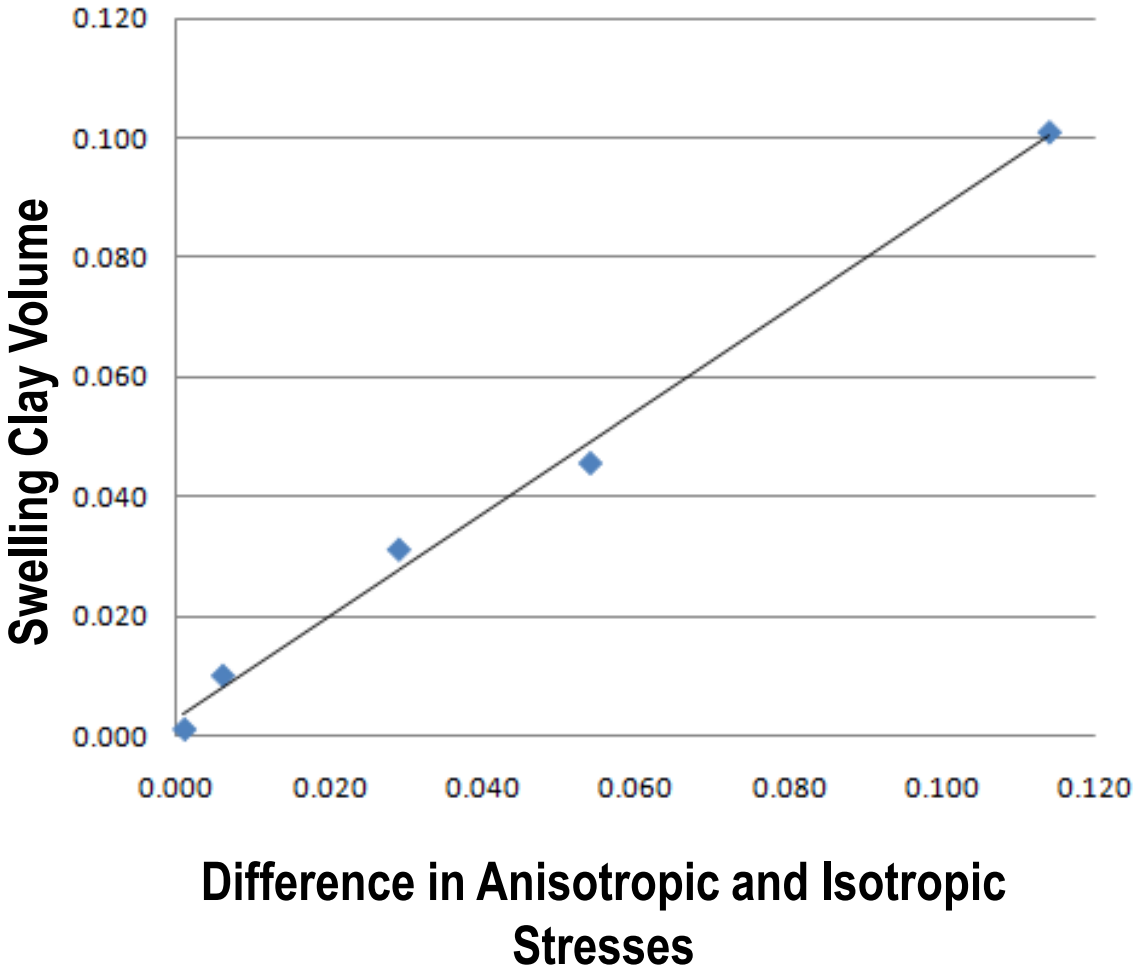

Good relationship between the clay volume and the difference Anisotropic and Isotropic closure stress models

Correlation is weakest at low clay volumes where the rocks are more isotropic

Increasing the clay volume increases the error in the isotropic stress model



# Completion Quality – Clay Type



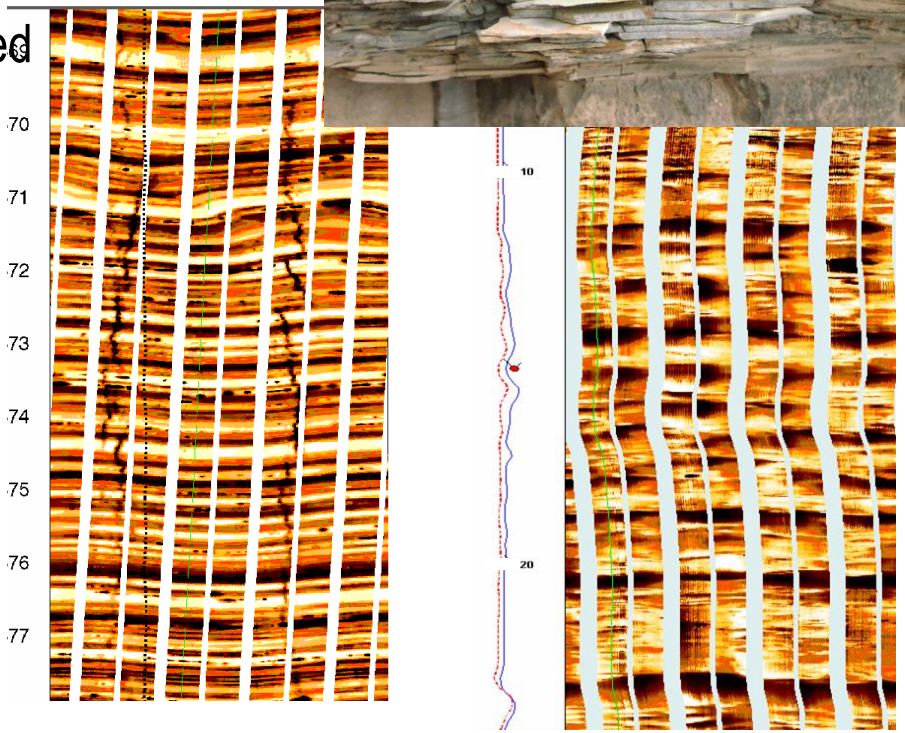

Excellent relationship between the volume of swelling clay and the difference between the Anisotropic and Isotropic closure stress models

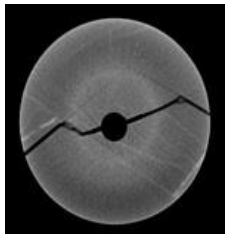
Small amounts of swelling clays dramatically increase closure stress

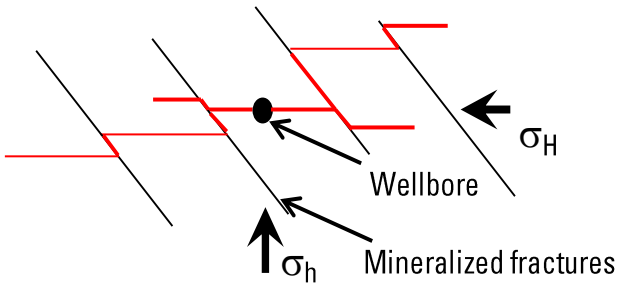
- (not captured with Isotropic models)

# Completion Quality – Role of Fabric

- Rock fabric can be complex
- Fractures can be open, healed, drilling induced or reactivated
- Clay is usually found in layers
- Mud systems need to limit activation of healed systems
- All planes of weakness need to be mapped
- Regional stress needs to be understood



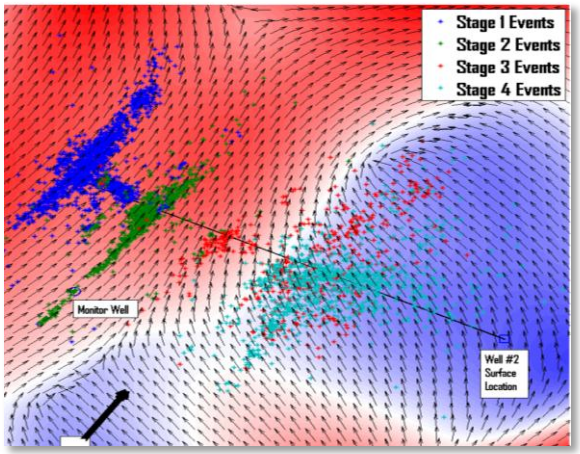





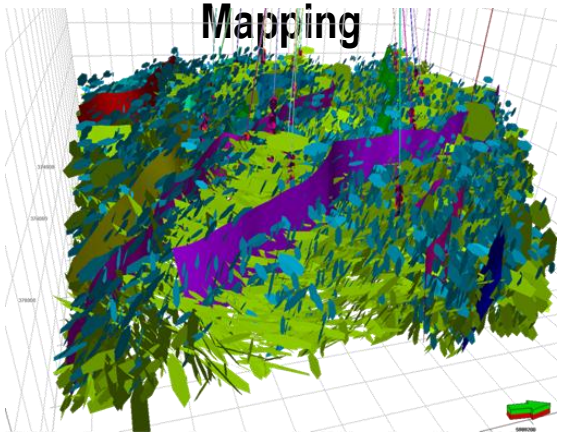


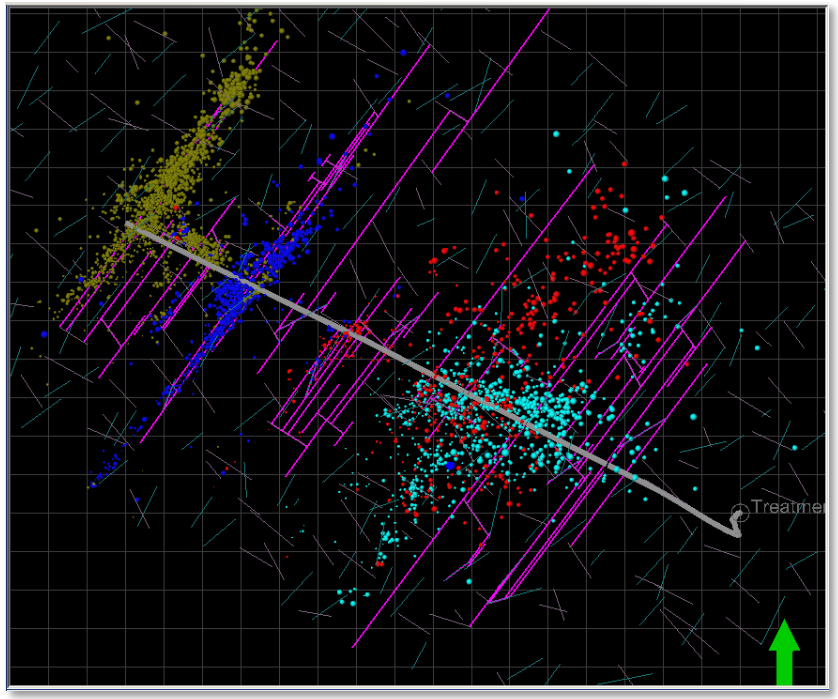

# Completion Quality – Creating Surface Area

## Creating Productive Surface Area




**3D Stress Mapping**





**Complex Hydraulic Fracture Simulations**

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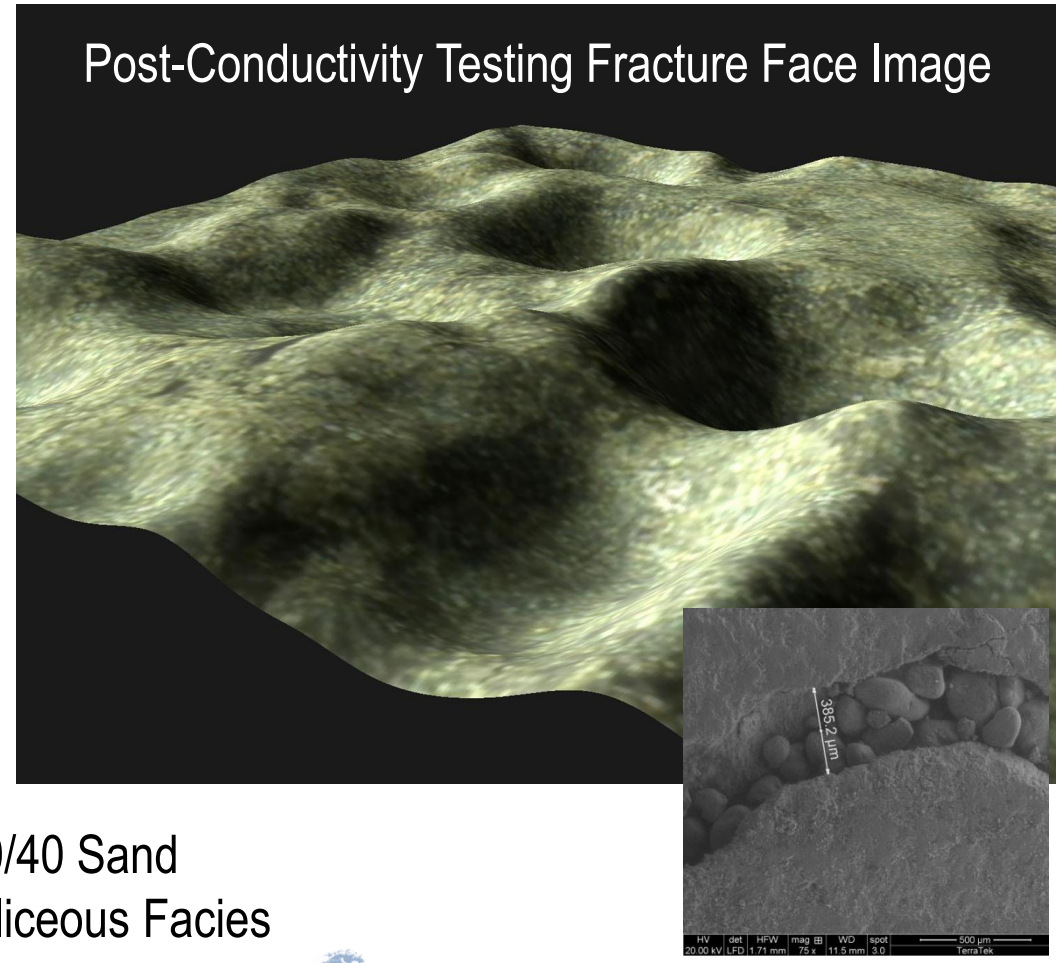
# Completion Quality – Maintaining Surface Area

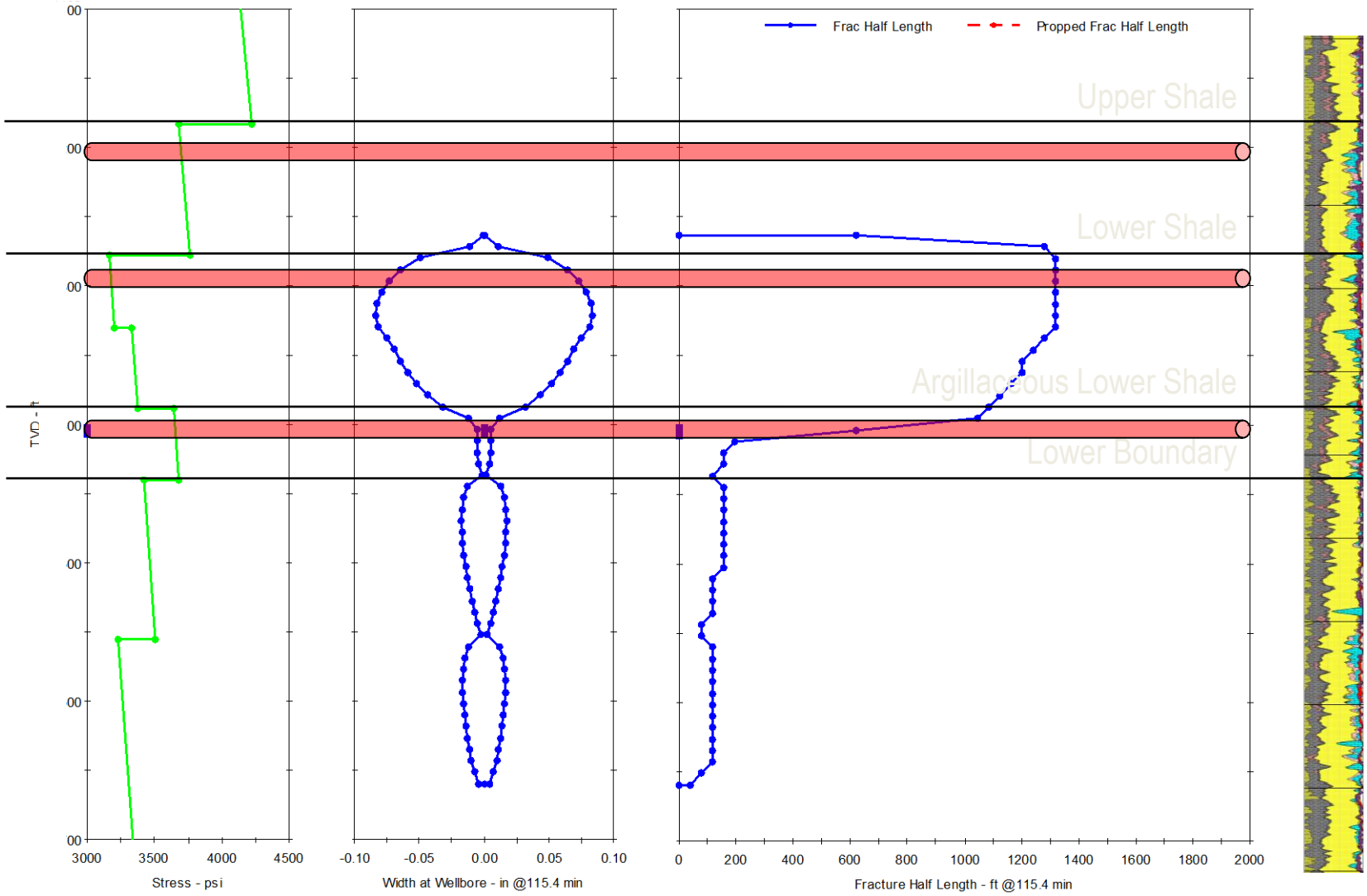
20/40 Resin Coated Sand
Argillaceous Facies




20/40 Sand
Siliceous Facies



# Completion Quality – Well Placement



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Integration

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- Organic content
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- Porosity
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- Water saturation
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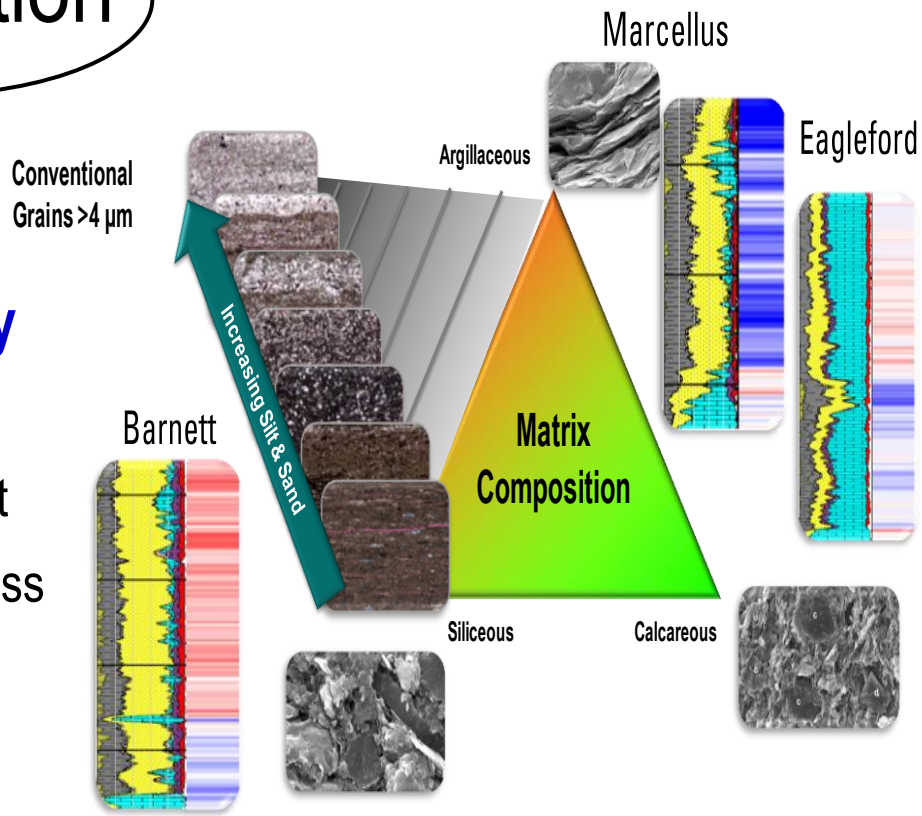
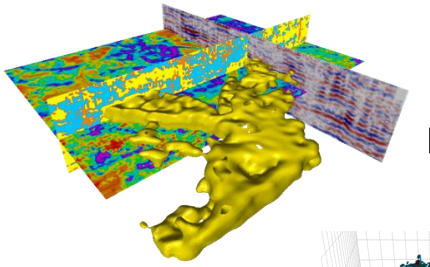
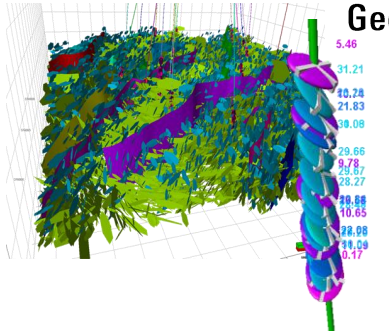




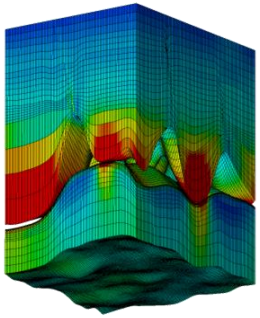

# Exploration Challenge – Integrated Workflow



Geophysics
Petrophysics



Geology



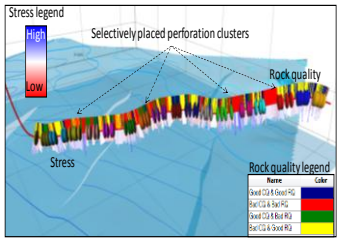
Geomechanic
al Model

- Reservoir Quality Model
- Completion Quality Model
- Geology Model
- Geomechanical Model
- All Integrated into a Petrel Model
- **No Production Yet!!!**

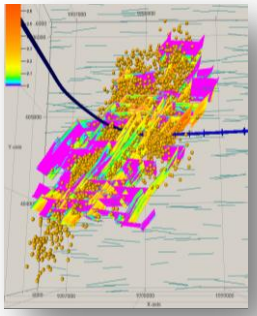


# Exploration Challenge: Completion & Stimulation Design

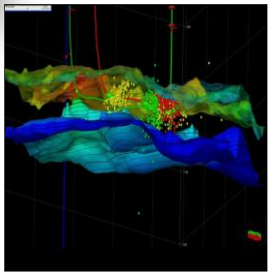
- Reservoir Quality Model
- Completion Quality Model
- Geology Model
- Geomechanical Model
- All Integrated into a Petrel Model
- **Can this Resource Produce ??**




*Staging & Perforating*

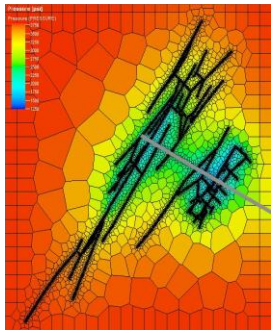


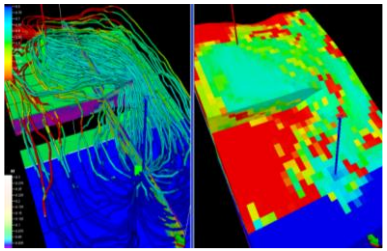
*Complex Hydraulic Fracture Models*



*Microseismic Mapping*

*Automated Gridding*





Production Forecasting

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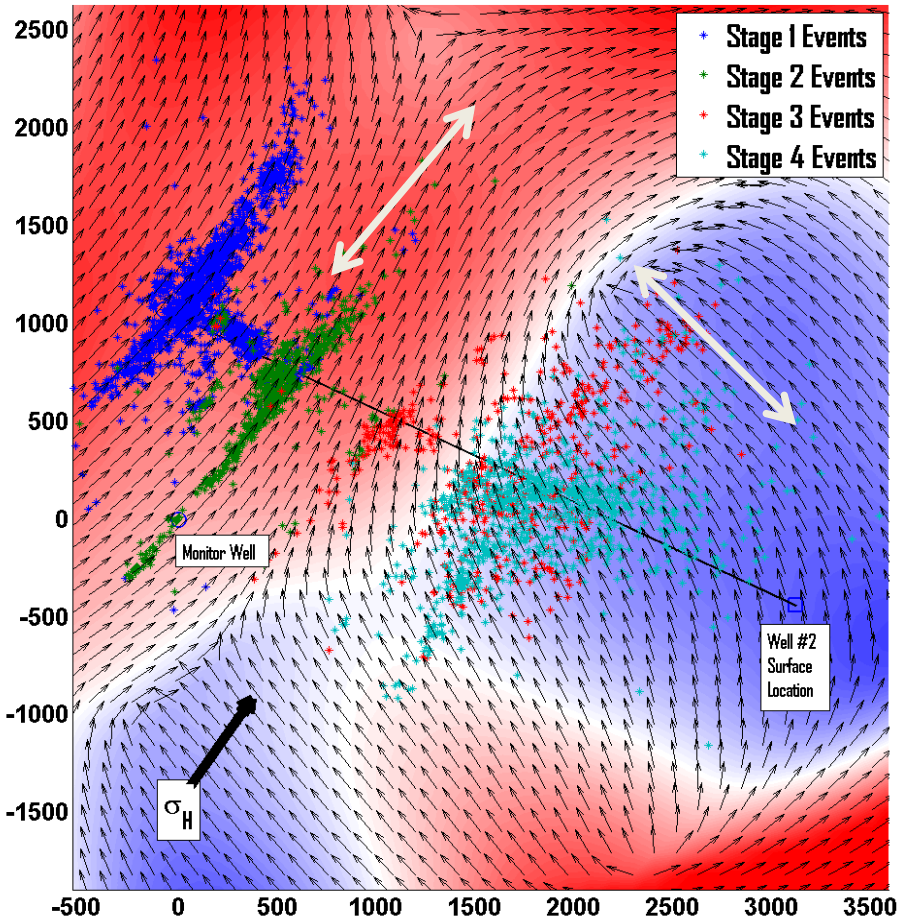
# Exploration Challenge – Effective Stimulation




Variation in natural fracture orientation & stress anisotropy

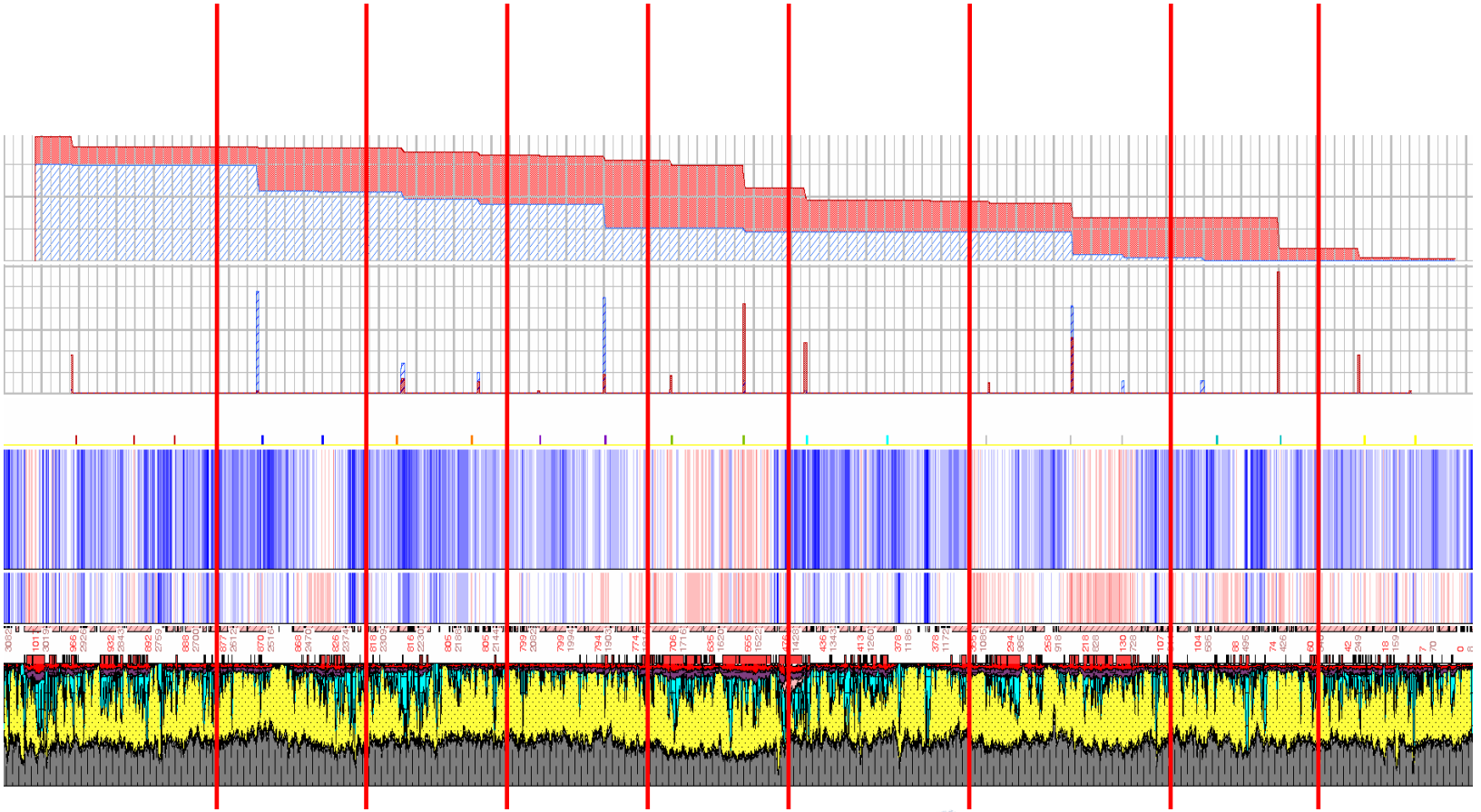
## Fracture geometry driven by:

- Subtle changes in structure
- Subtle changes in stress anisotropy
- Change in natural fracture orientation
- Subtle changes in texture



# Exploration Challenge – Evaluation of Results

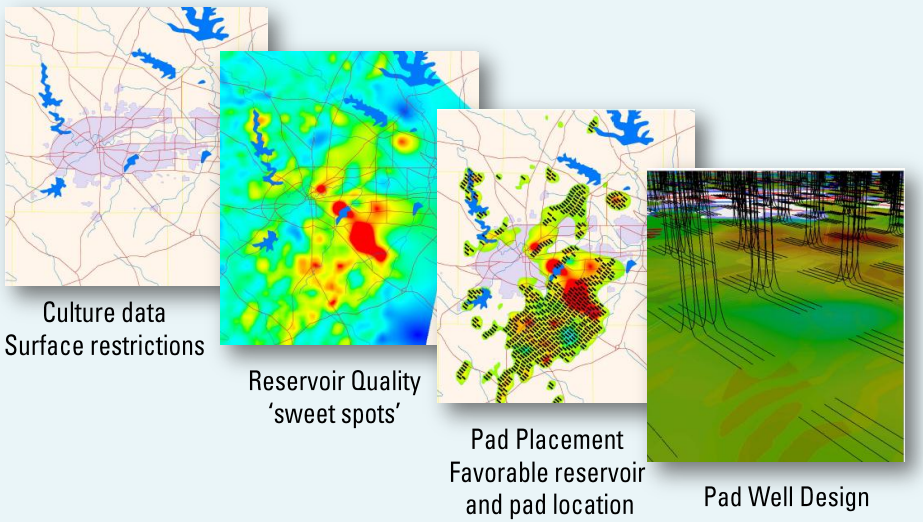
Where is production?  What does it tell us?  Can we improve it?



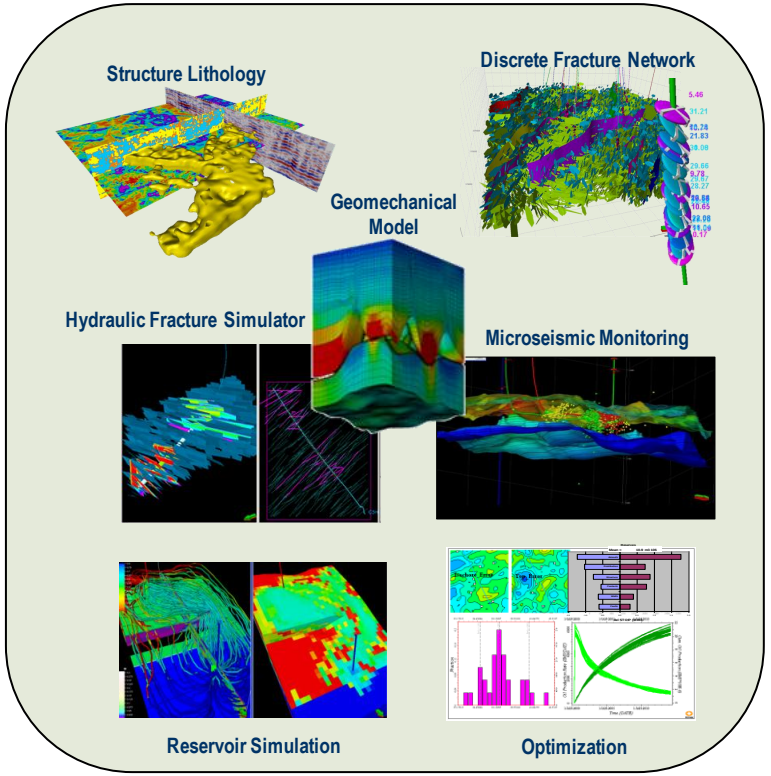
# Exploration Challenge

## Integration of Results → Production→Cost Reduction

### Platforms to Reduce Footprint




### Platforms to Optimize Recovery




Shale Field Development Plugin Package

Petrel 2011

Mangrove - Integrated Completion Design

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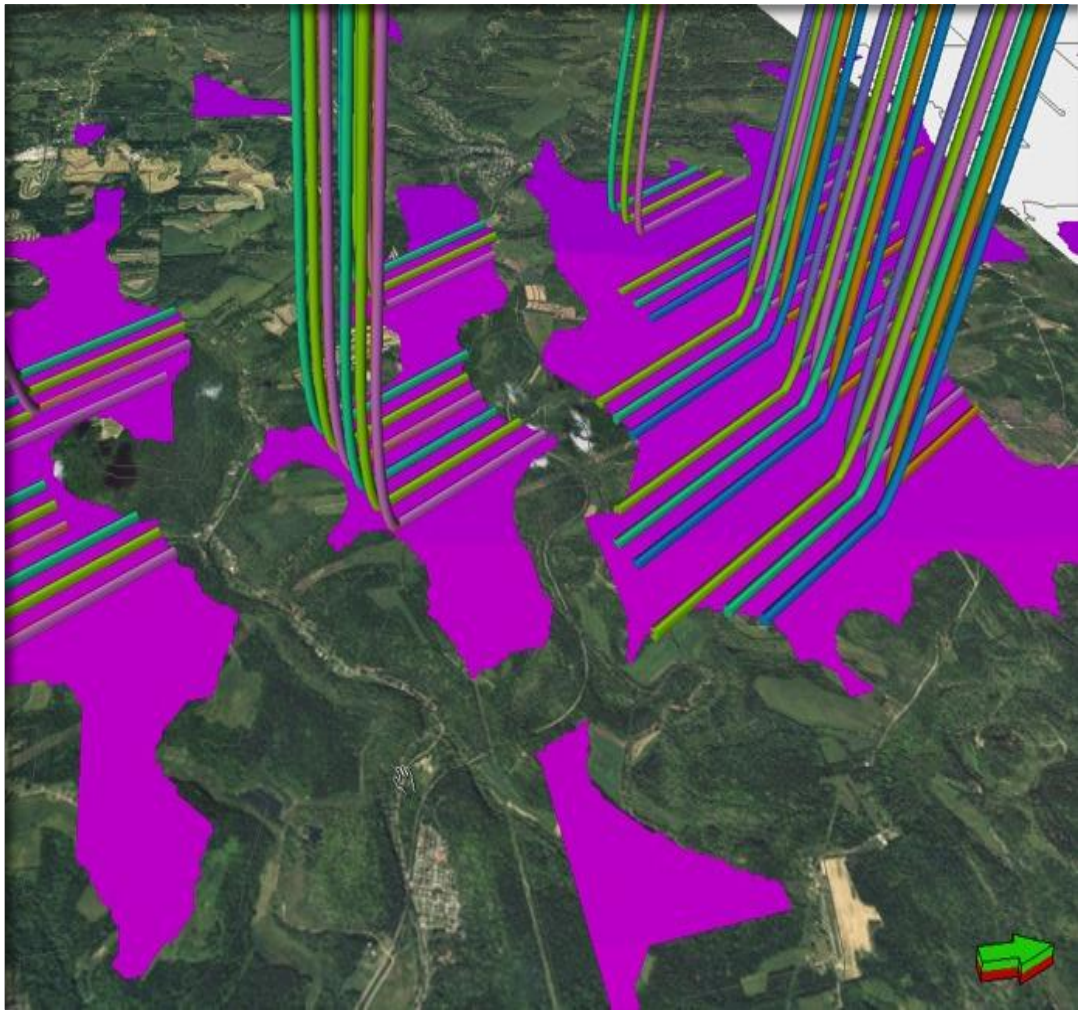
# Our goal: Economic Unconventional Production

*Development wells*

- Drilled in the right place
- Right size completion
- Good frac job
- Sustained commercial production





# Exploration Challenge – Summary

- Shale is heterogeneous at all scales
- Reservoir Quality and Completion Quality can be defined.
- Data integration is used to define and exploit the reservoir.
- All Shale is different
- Good Reservoir Quality does not equal Good Completion Quality
- Reservoir Quality cannot be Engineered
- Completion Quality can be Engineered to the limit of current technology

**Integration is the Key to Unlocking Unconventional Production**



# Thank you for your attention