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# Frac Model Calibration for Conventional and Unconventional Rocks

Leen Weijers

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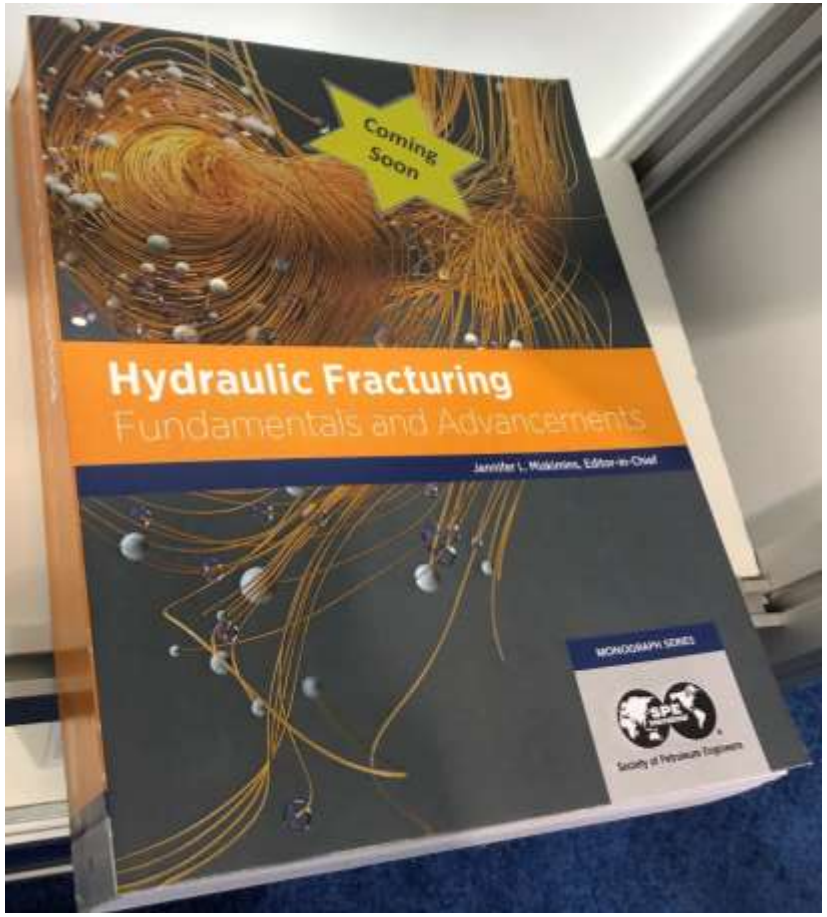
# Outline

- Introduction
- Why Model?
- 1st Calibration Cycle – Pressure Qualification
- 2nd Calibration Cycle – Net Pressure Matching
- 3rd Calibration Cycle – Fracture Mapping
- Frac Model Calibration Case Histories
- Conclusions




**Chapter 4: Frac Modeling**

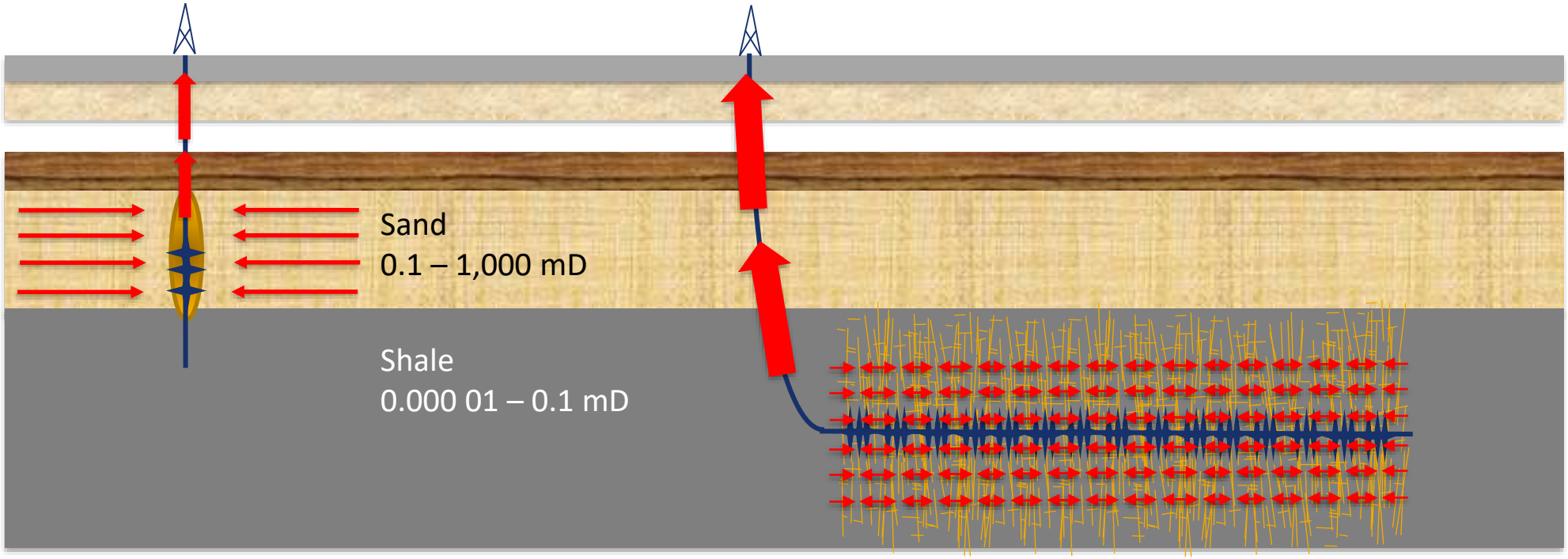
# Conventional vs Shale Frac'ing

- 1947 – present
- Higher permeability sand – **Moving the hydrocarbon molecule to the frac**
- Vertical wells, mostly single stages
- Focus on conductivity


# Conventional vs Shale Frac'ing

- 1947 – present
- Higher permeability sand – **Moving the hydrocarbon molecule to the frac**
- Vertical wells, mostly single stages
- Focus on conductivity

- ~2000 – present
- Low permeability shale – **Bringing the frac to the hydrocarbon molecule**
- Multi-stage horizontal wells
- Focus on complexity – "2 miles of plumbing"

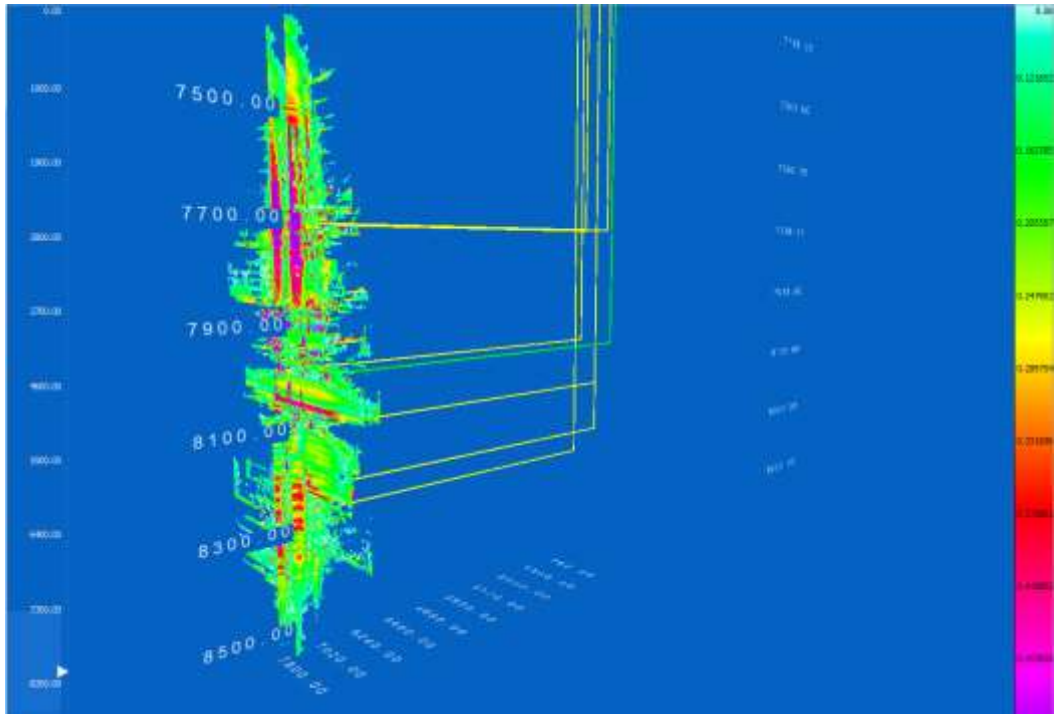


# Why Model Hydraulic Fracs?

- Tier 1: “Get the job away”
- Tier 2: Optimize production economics

How?

- Improve proppant placement
- Improve well-to-fracture connectivity
- Height coverage optimization
- Conductivity vs half-length / complexity trade-offs ($F_{cD}$)




**Height Coverage Optimization**

# Why Model Hydraulic Fracs? Optimize Frac Dimensions

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## Simplified Design Metric: Dimensionless Fracture Conductivity

$$F_{cD} = \frac{k_f w}{k L_f}$$

$$= \frac{\text{"Fracture Throughput"}}{\text{"Reservoir Deliverability"}} = \frac{\text{"Traffic Throughput"}}{\text{"Traffic Inflow"}}$$

$k_f w$: Fracture Conductivity, mD ft

$k$: Formation Permeability, mD

$L_f$: Fracture Half-Length, ft

**What We Want**


# Why Model Hydraulic Fracs? Optimize Frac Dimensions

## Simplified Design Metric: Dimensionless Fracture Conductivity

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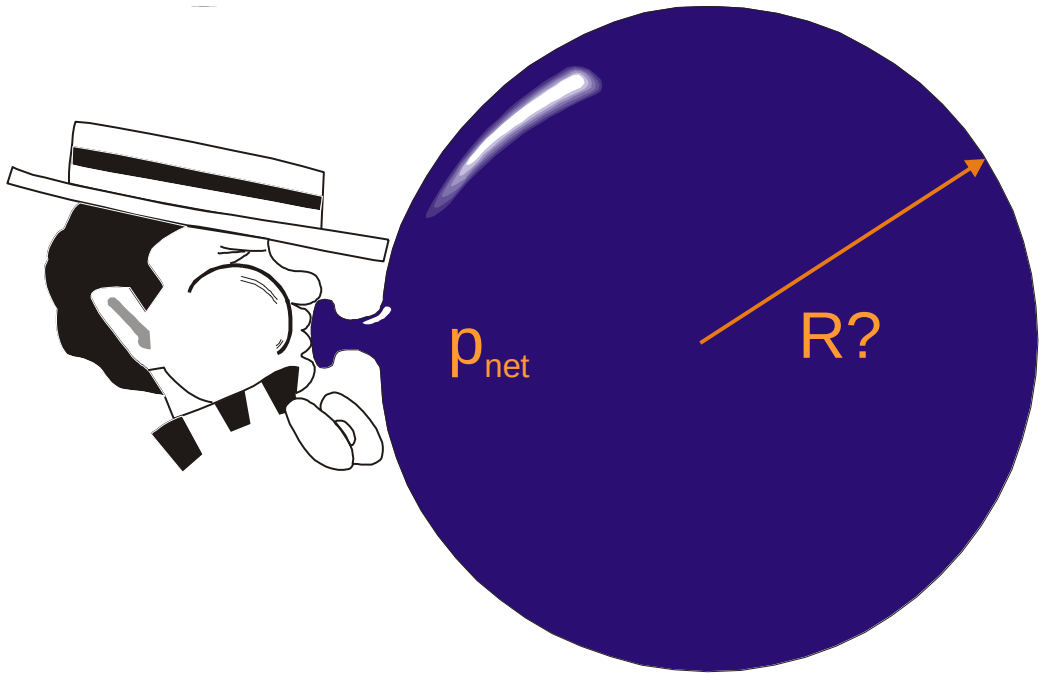
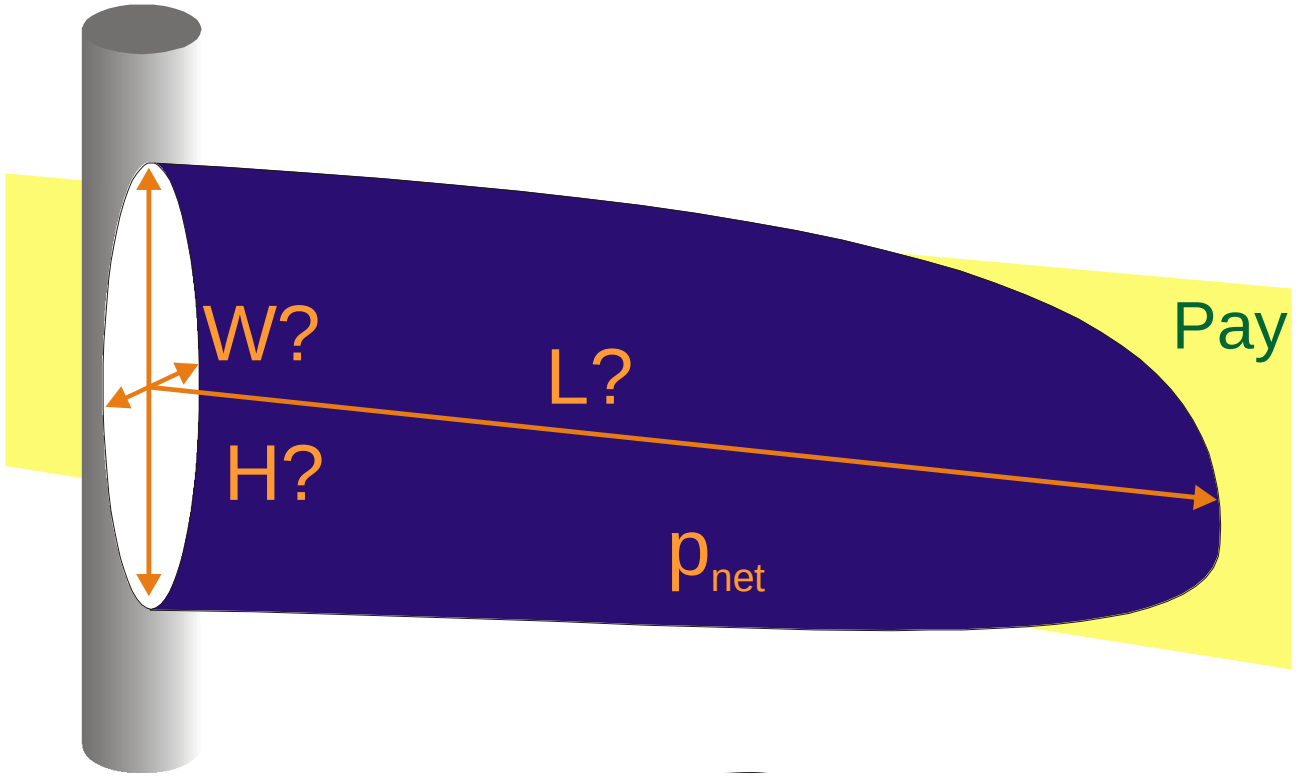
**What We (Often) Get**


# Using Indirect Measurements to Determine Dimensions



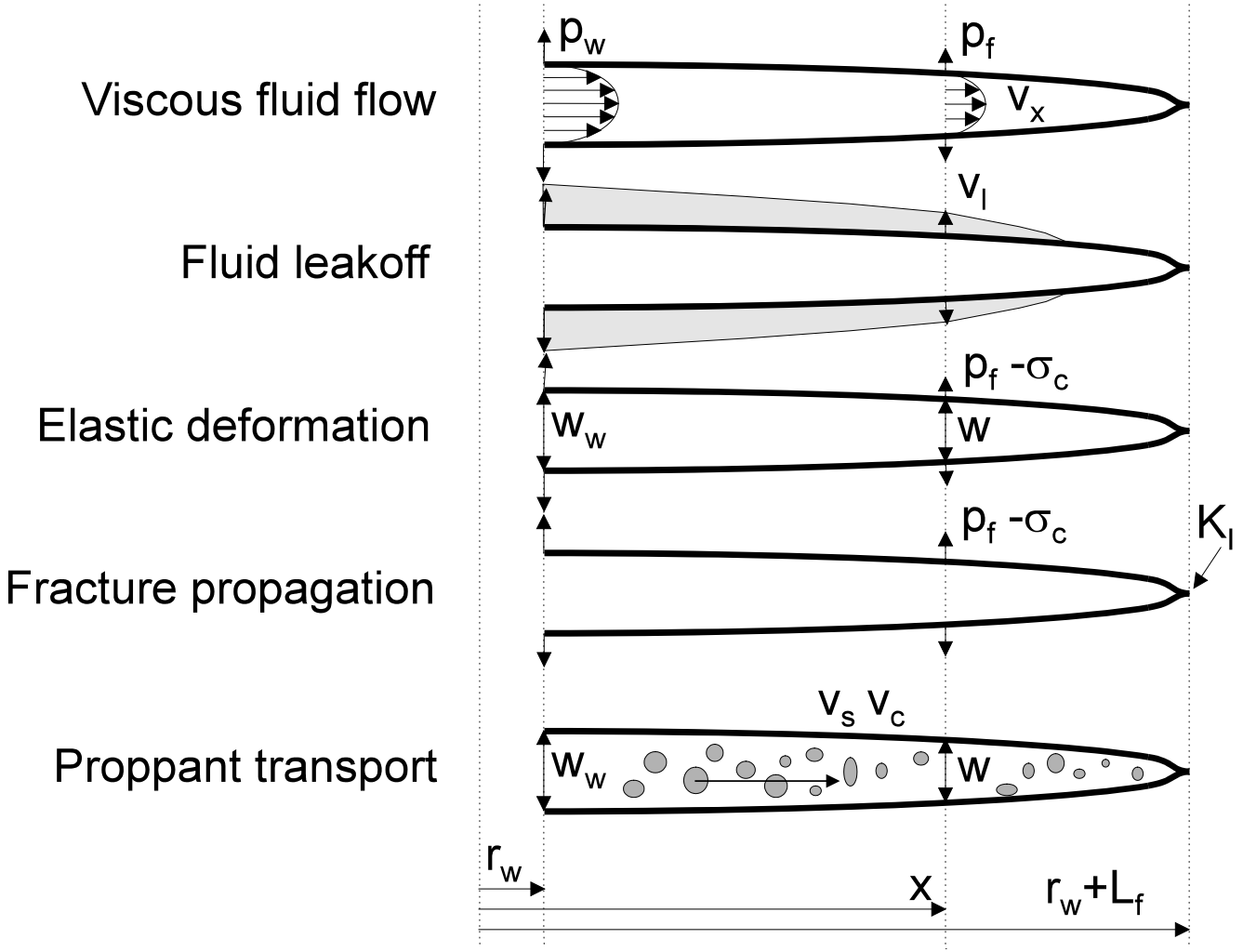

Injected Volume
Balloon Elasticity
Net Pressure $P_{net}$

} Radius R

Injected Volume, Efficiency
Layer Rock Properties
Net Pressure $p_{net}$

} Length L,
Height H,
Width w

# Hydraulic Fracture Propagation – Physical Processes




**Key relationships**

(Darcy's Law)

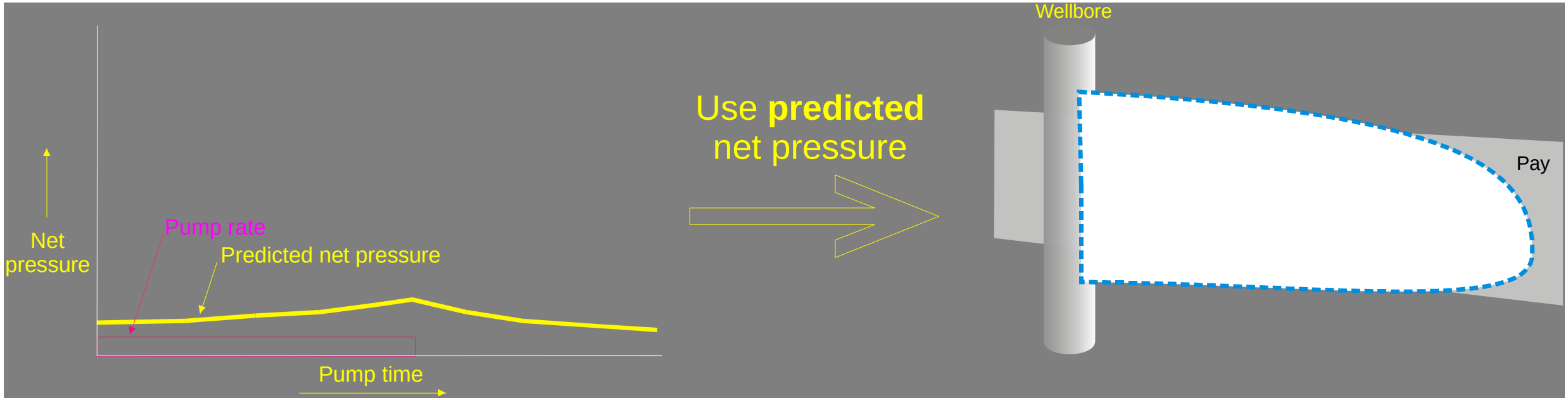
(Mass balance)

(Sneddon equation)

# Fracture Modeling Evolution

## Modeling without Real-Data Feedback

- Early designs (pre-1980) did not incorporate feedback from real data
- Frac modelers thought fracs would mostly stay in zone

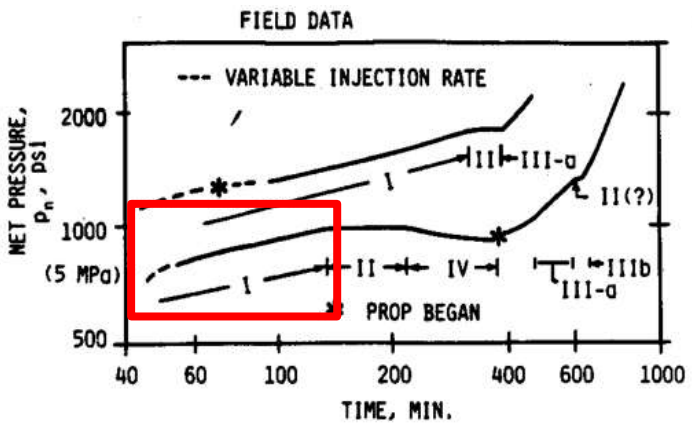


# Fracture Modeling Evolution

## The 1st Model Calibration Cycle – Pressure Qualification

- Early designs (pre-1980) did not incorporate feedback from real data
- Frac modelers thought fracs would mostly stay in zone
- Observed net pressure trends could be evaluated

- Nolte (1979) linked net pressure progression over time to fracture growth modes
  - Mode I represents desirable in-zone growth




**Nolte net pressure behaviors**

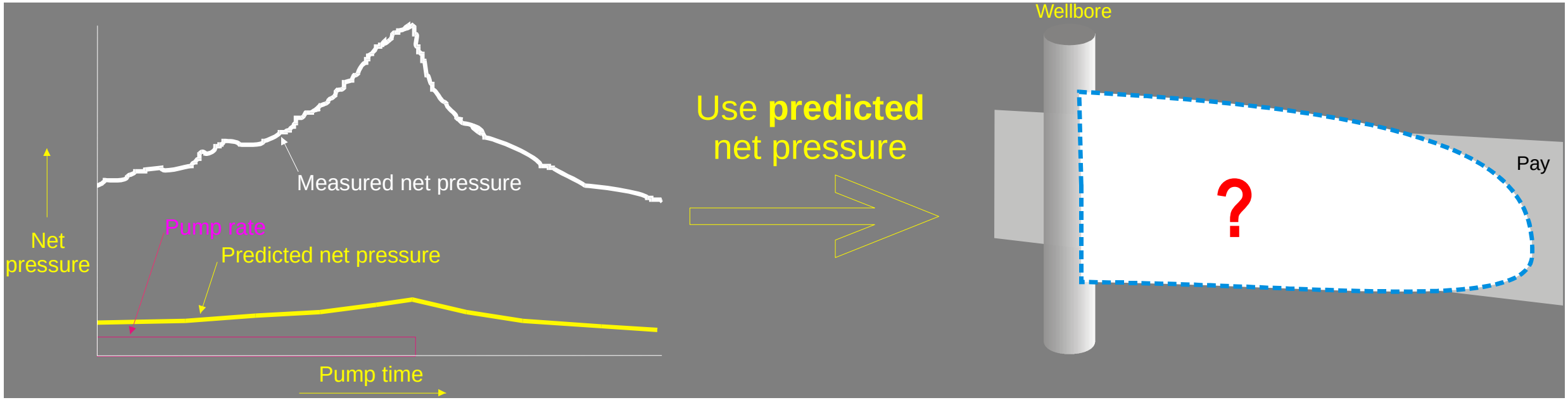
| Growth Mode | Description | Slope |
|---|---|---|
| I | No height growth | 1/5 |
| II | Height growth / fissure opening | 0 |
| III | Tip screen-out | 1 |
| IV | Unrestricted height growth | Negative |

**Nolte growth modes**

# Fracture Modeling Evolution

## The 2nd Model Calibration Cycle – Net Pressure Matching

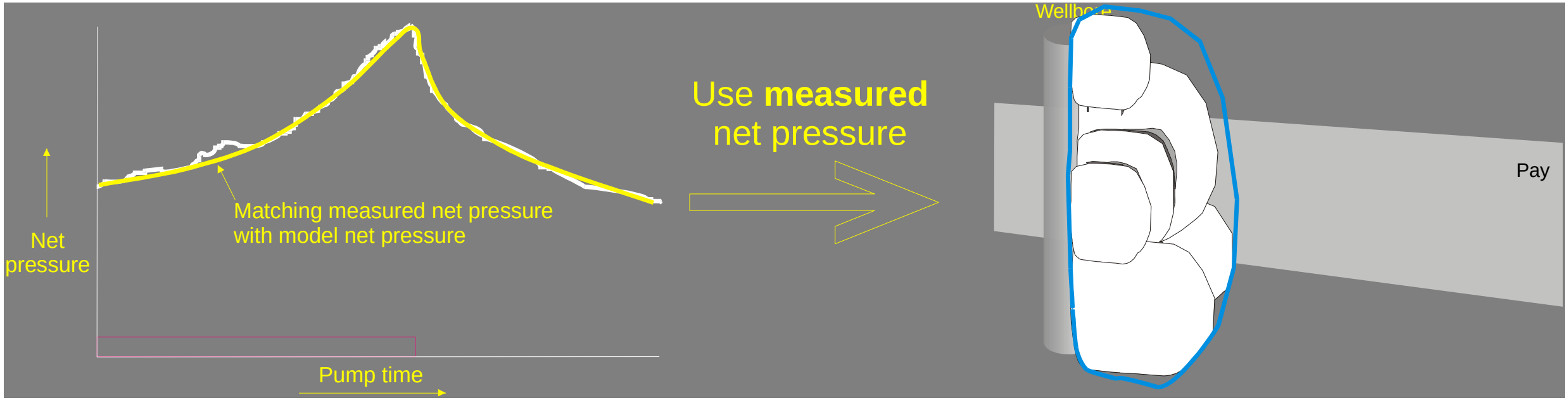
- Early designs (pre-1980) did not incorporate feedback from real data
- Frac modelers thought fracs would mostly stay in zone
- However, measured net pressure generally MUCH higher than model net pressure



# Fracture Modeling Evolution

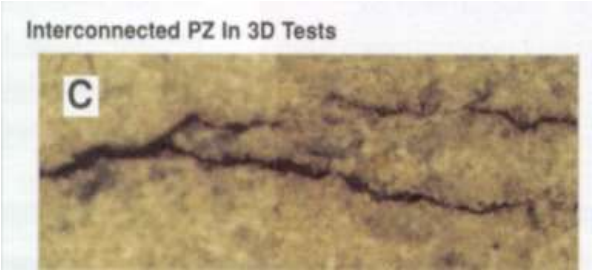
## The 2nd Model Calibration Cycle – Net Pressure Matching

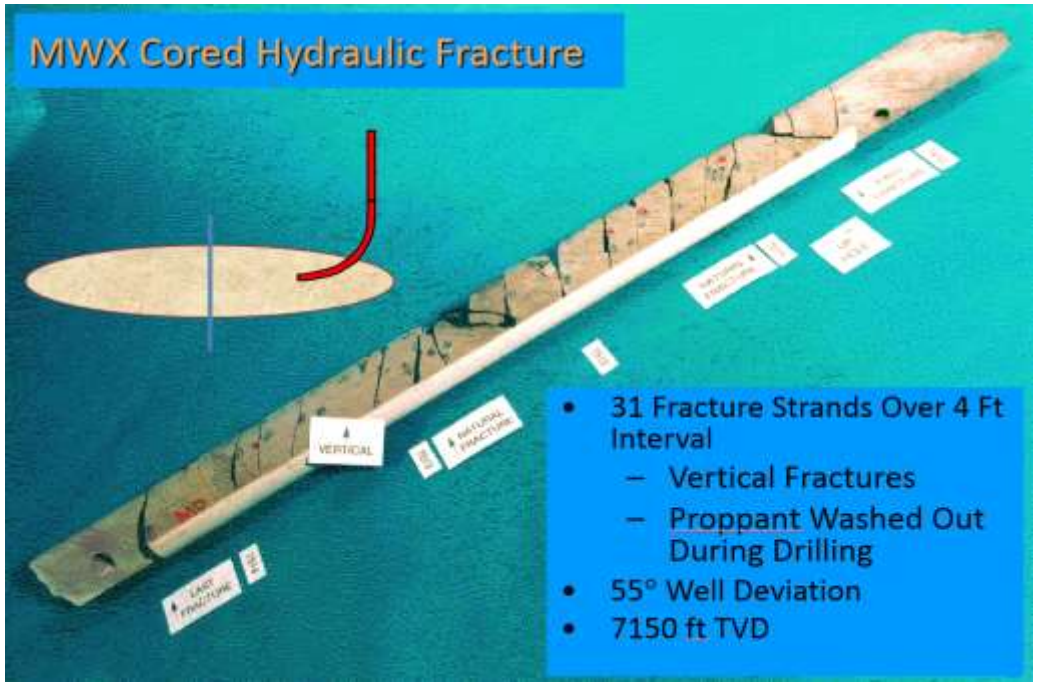
- Net pressure history match can be obtained by incorporating new physics into fracture models
  - Multiple fractures, tip effects
- With the right physics, inferred geometry has a better chance to be correct



# Multiple Fractures and Tip Effects

- Shlyapobersky et al. (1992, 1998) first observed **process zone**
  - Fluid lag region
  - Cohesive zone ("bridging")
  - Plastic deformation
  - Opening of micro-fractures
- Multiple fractures first observed in minebacks / core throughs by Warpinski & Teufel (1984)
  - Multiple initiation points
  - Bifurcation
  - Complexities at fracture tip

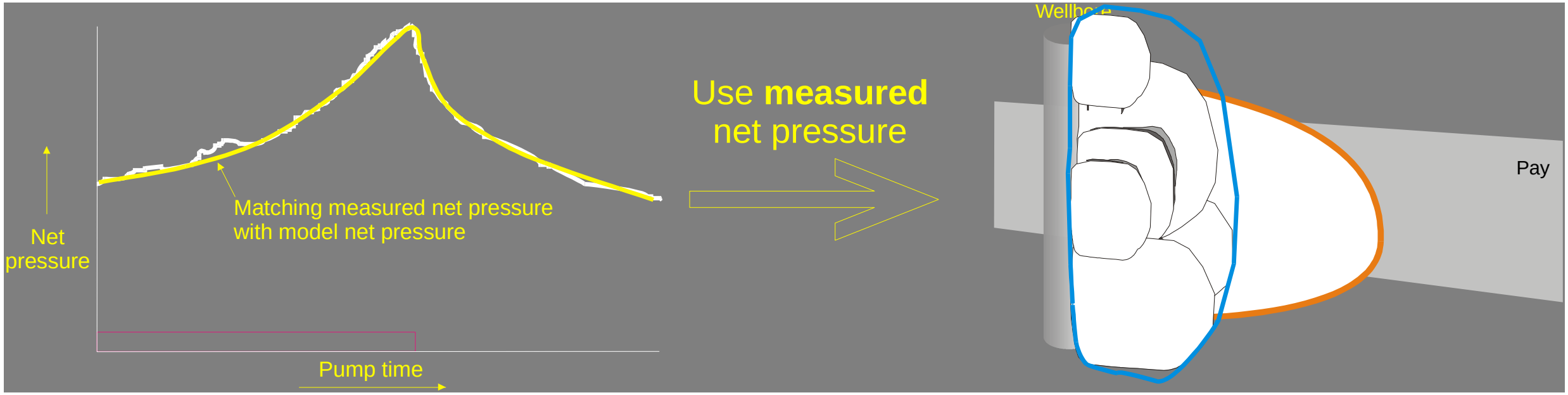



# Fracture Modeling Evolution

## The 3rd Model Calibration Cycle – Fracture Mapping

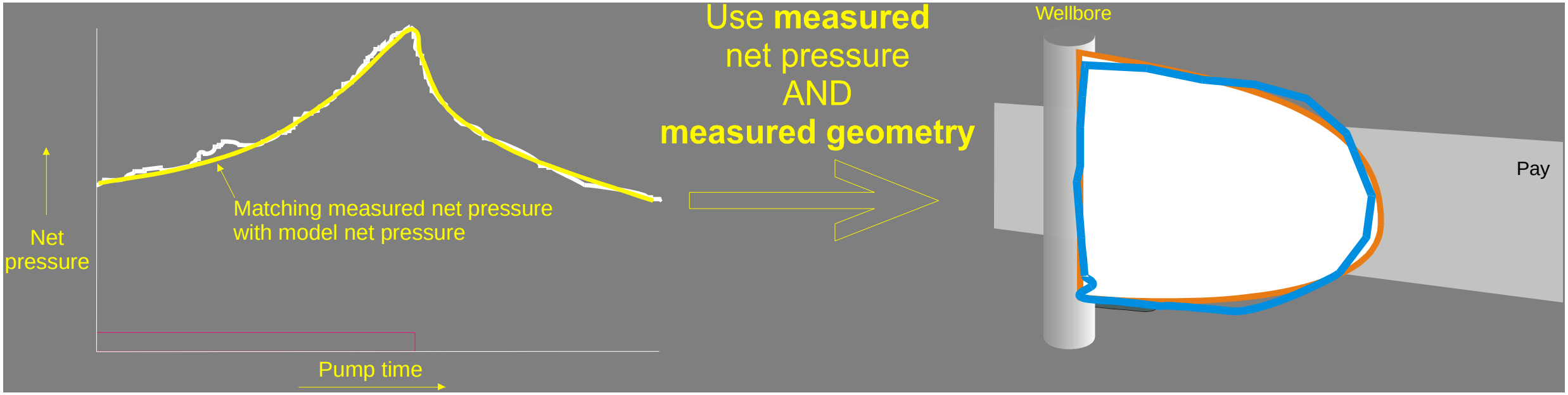
- Net pressure history matching can be implemented by adding new physics to fracture models
- With the RIGHT physics, inferred geometry has a better chance to be correct
- However, pressure matching-inferred geometry often less confined



# Fracture Modeling Evolution

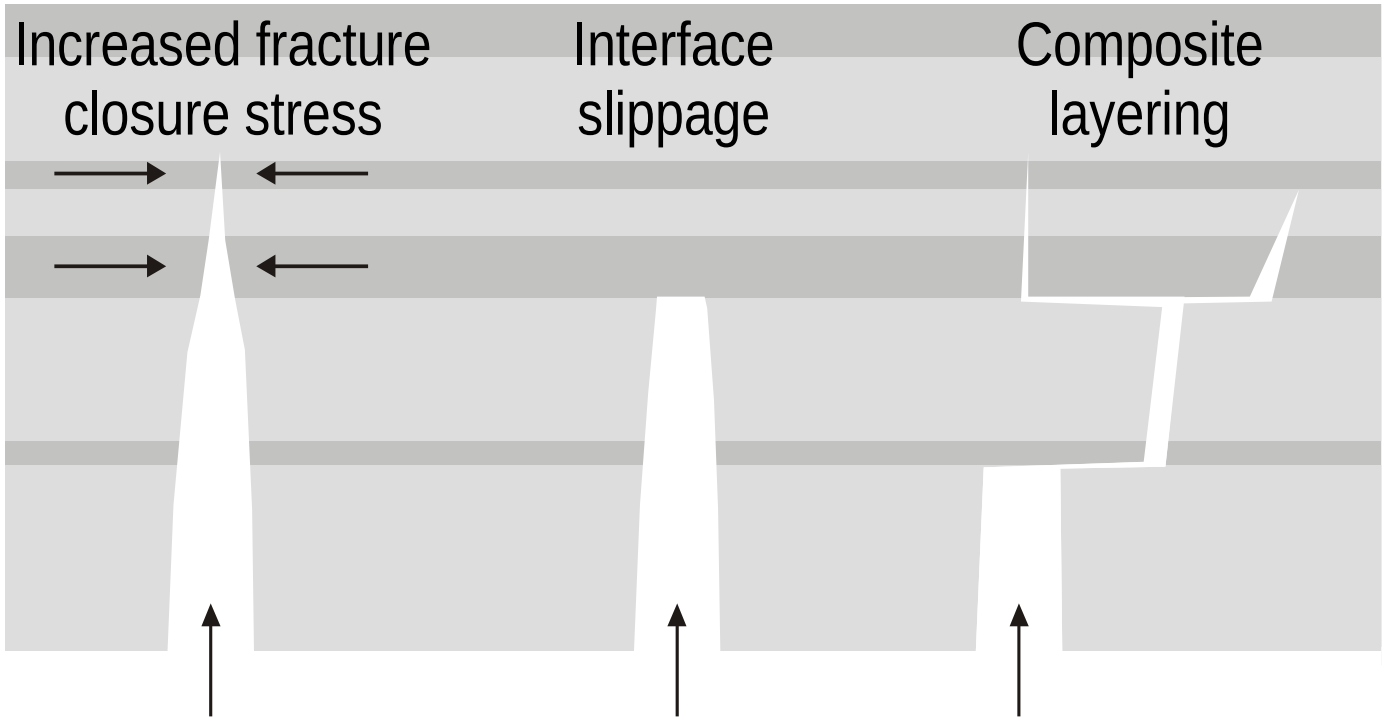
## The 3rd Model Calibration Cycle – Fracture Mapping

- Change physical mechanisms in model to match BOTH net pressure and directly observed fracture geometry
  - Layer interface effects
- Obtained a predictive tool that is firmly linked to actual growth behavior



# Composite Layering / Width Decoupling

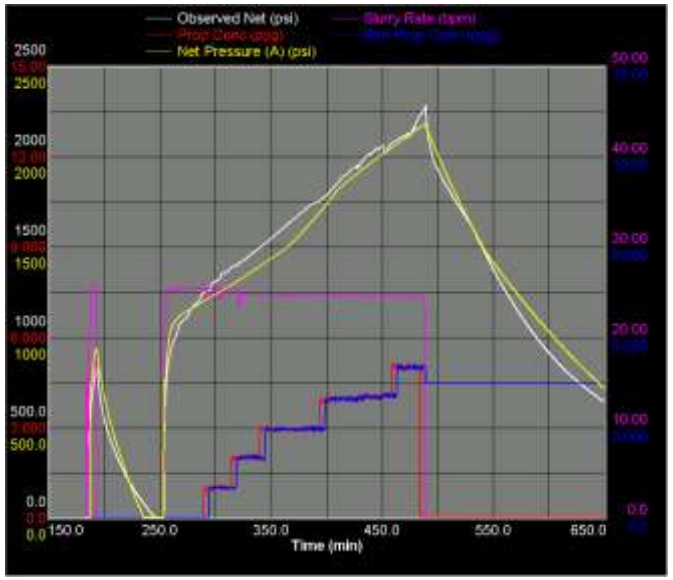
- Several researchers (Cleary 1980; Nolte and Smith 1981; Warpinski and Teufel 1984) speculated about additional confinement mechanisms
- Observed in minebacks
- Not incorporated in initial models

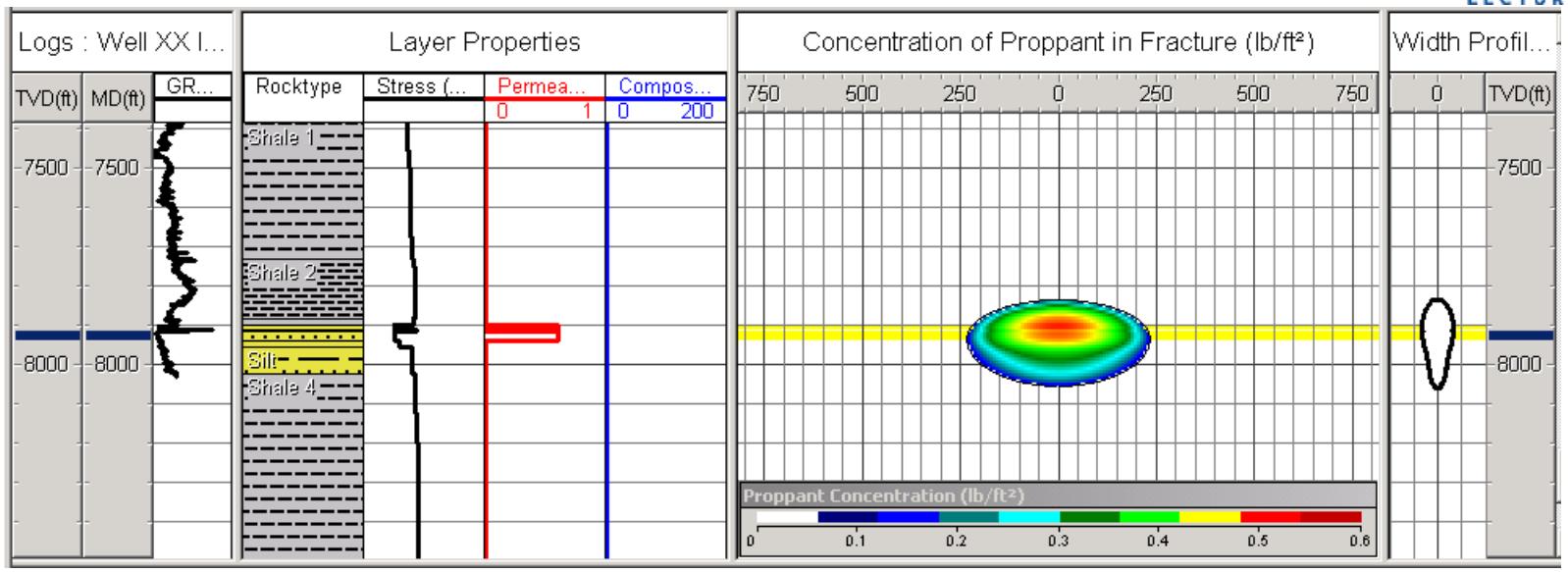



Confinement Mechanisms

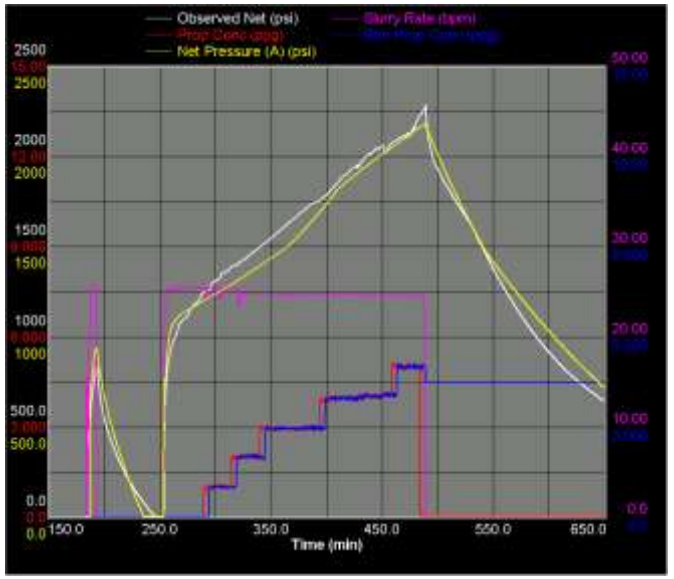
Composite Layering Effect

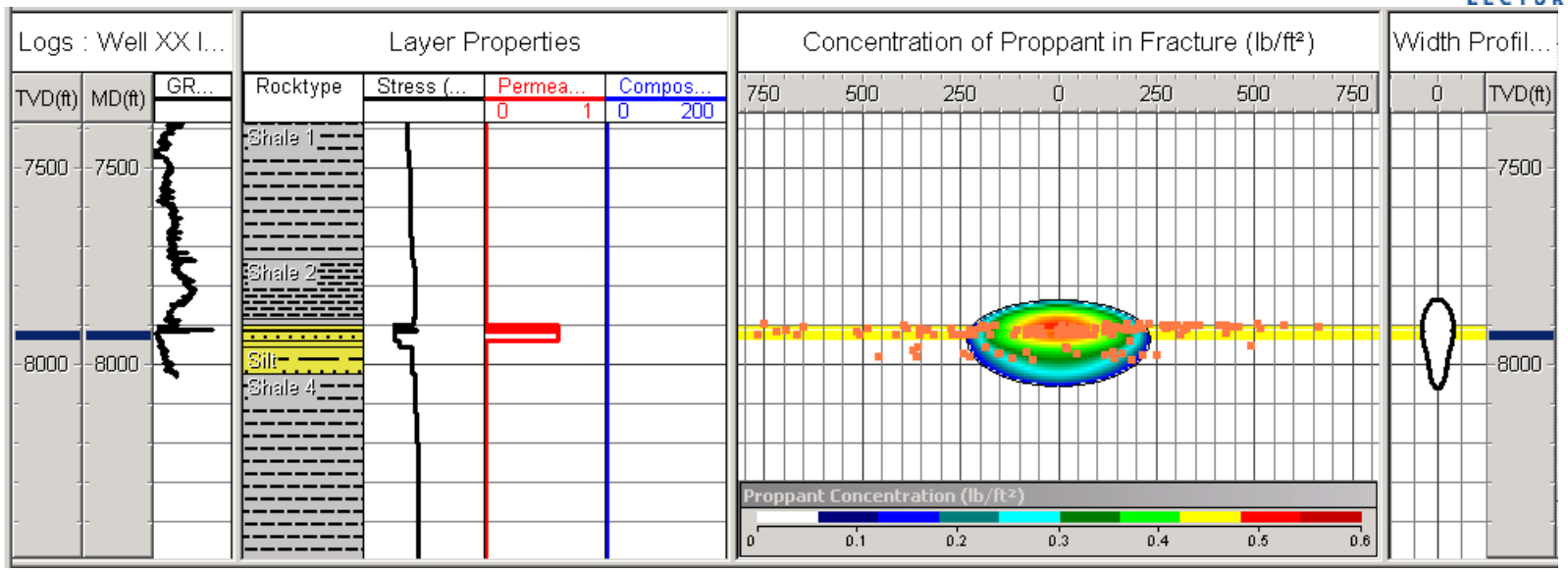
# Case Study 1: Calibration w/ Pressure Data

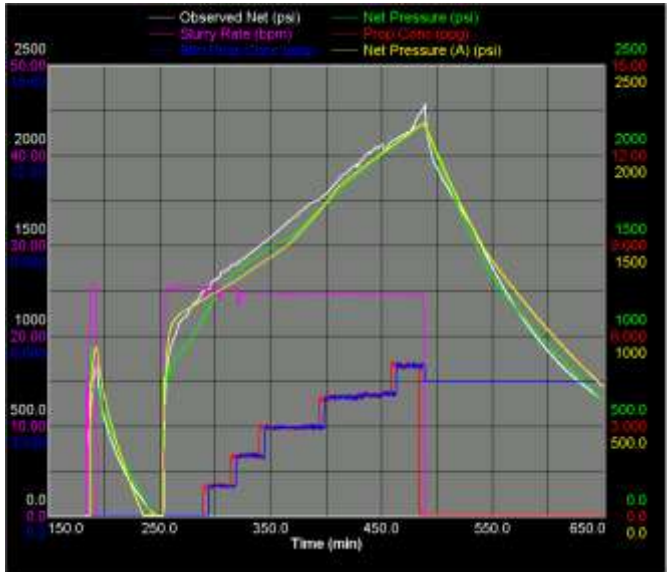


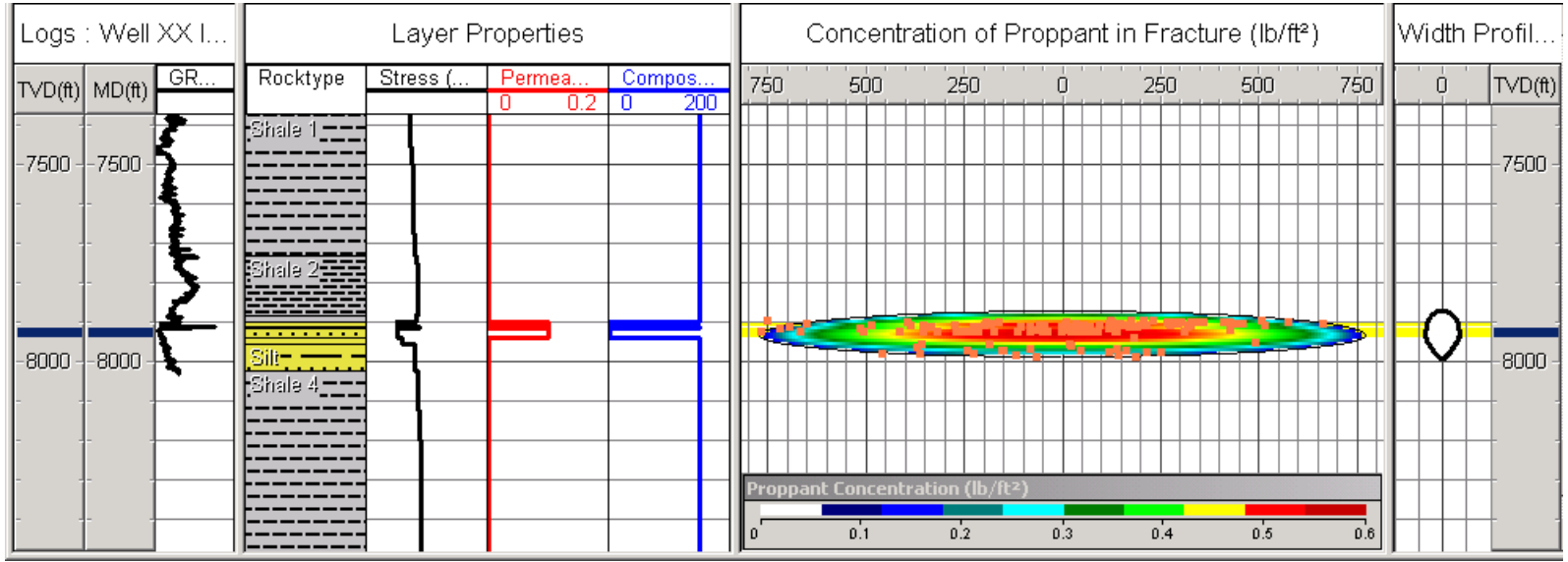



# Case Study 1: Calibration w/ Pressure & Micro-Seismic Data

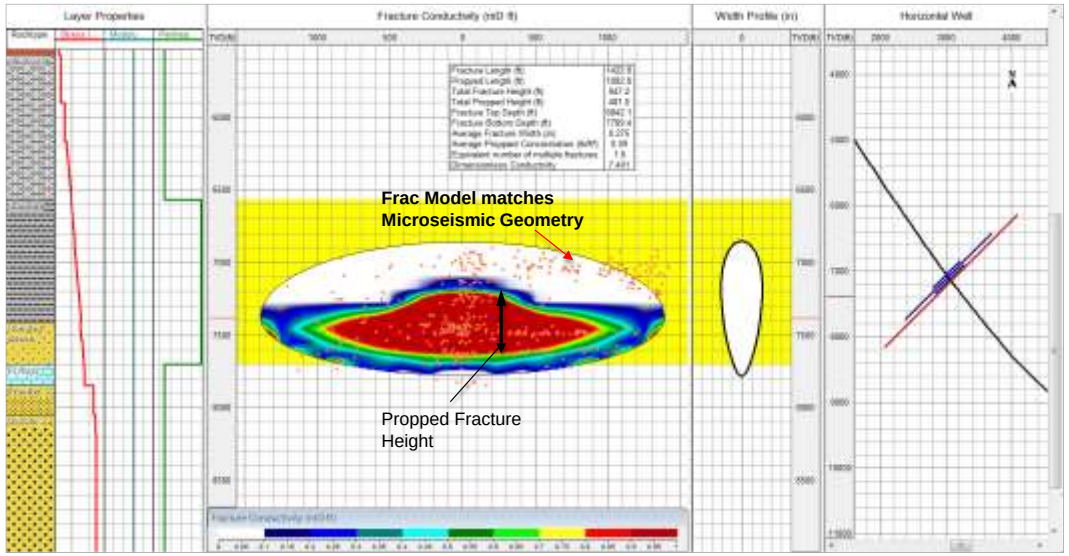


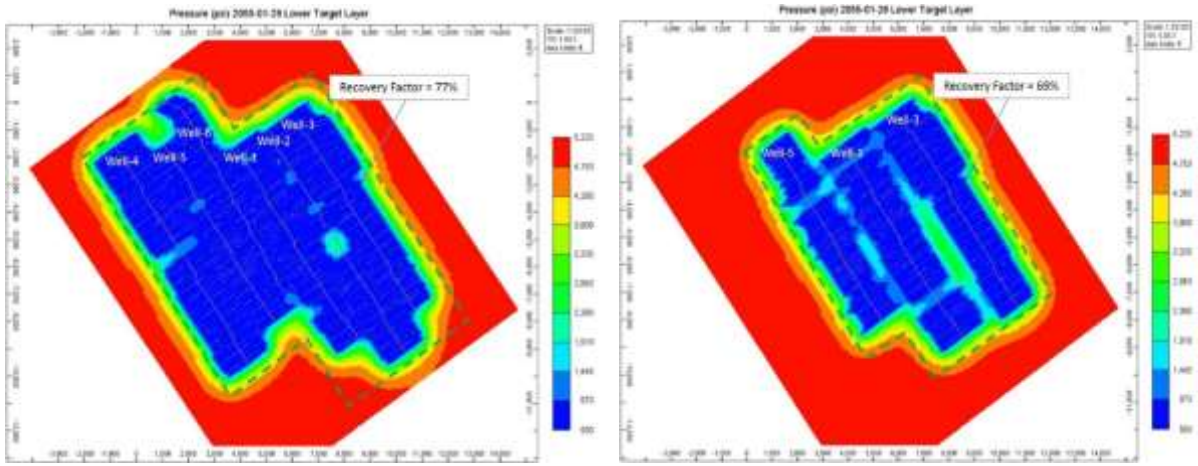



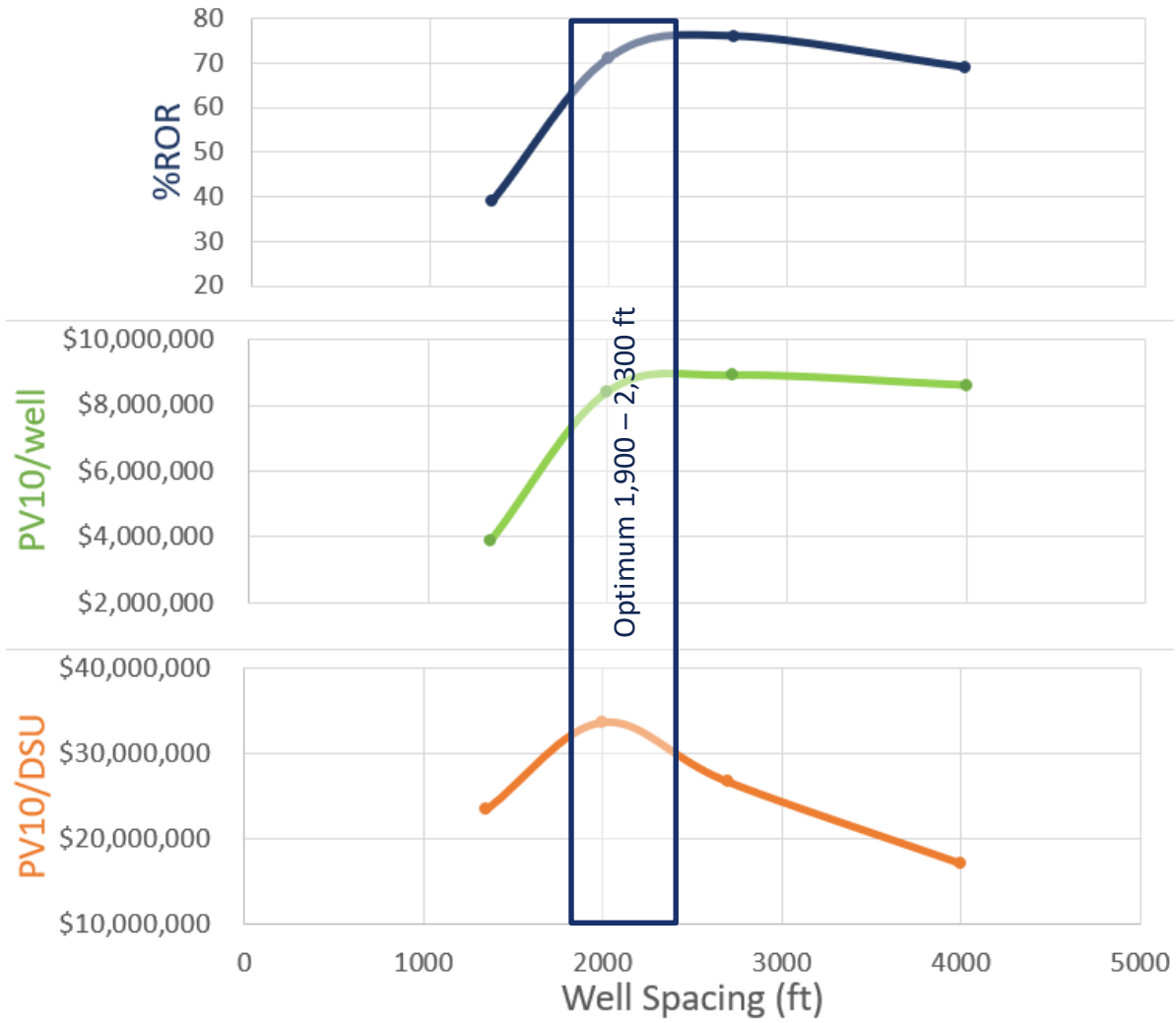
# Case Study 2: Calibration Critical for Well Spacing




**Frac Model Calibration**




**Spacing Scenario Evaluation**




**Economic Optimization**

Li *et al.* 2017 (SPE paper 184848)

# Calibration: Modeling and Measuring

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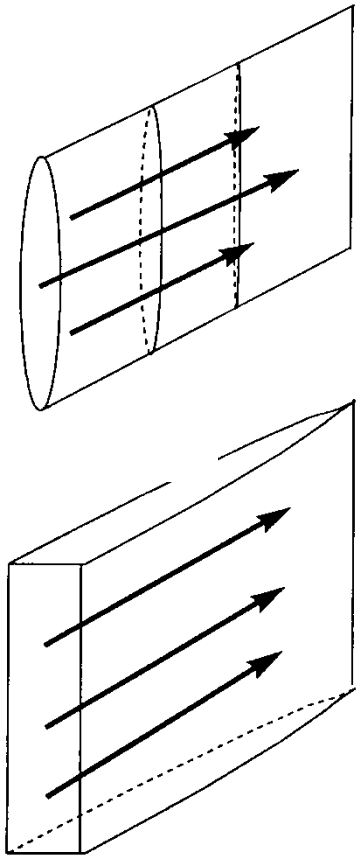
**Fracture Growth Models**
Predictive
Incomplete Physical Understanding

**Direct Diagnostics**
Not Predictive
Reflected Physical Behavior

**Calibrated models more realistically predict how fractures will grow for alternative designs**

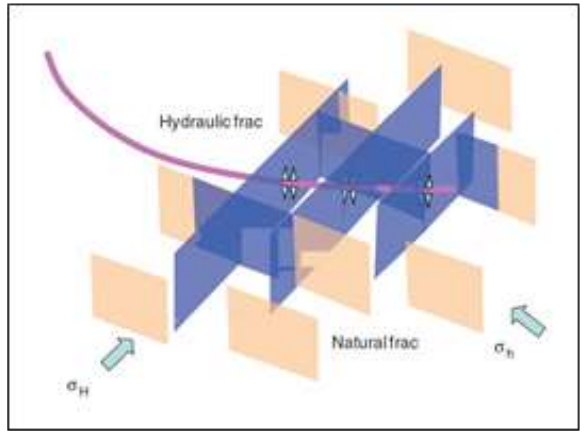
# Fracture Propagation Models for the Future…

- 2D models
  - Perkins, Kern and Nordgren (PKN)
  - Khristianovitch, Geertsma and De Klerk (KGD)
  - Radial Model
- 3D models
  - Pseudo-3D models
  - Back-of-the-envelope models
  - Parameterized 3D models
  - Full 3D models
- Non-planar models
- Complex models
- Fully-coupled models



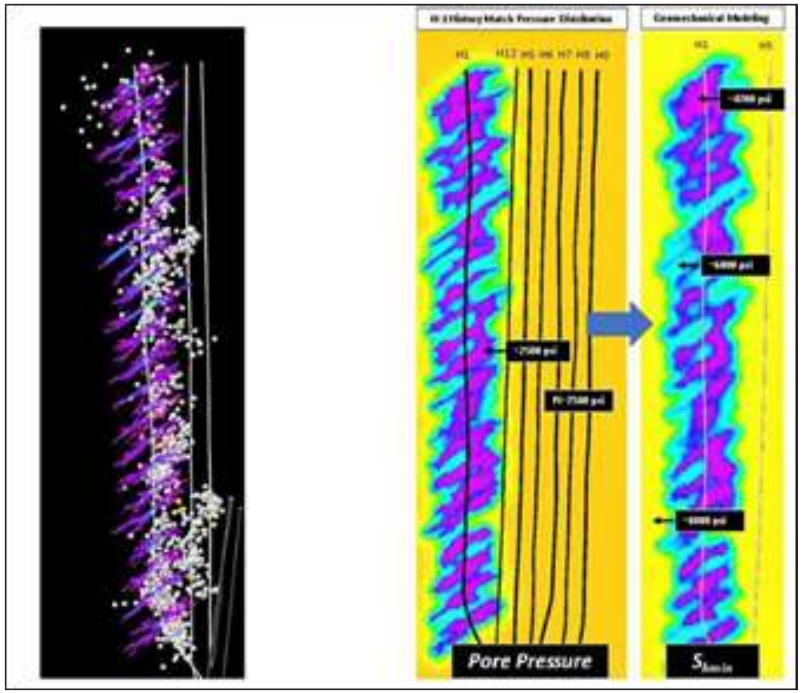
# Complex Fracture Models: New Paradigm?

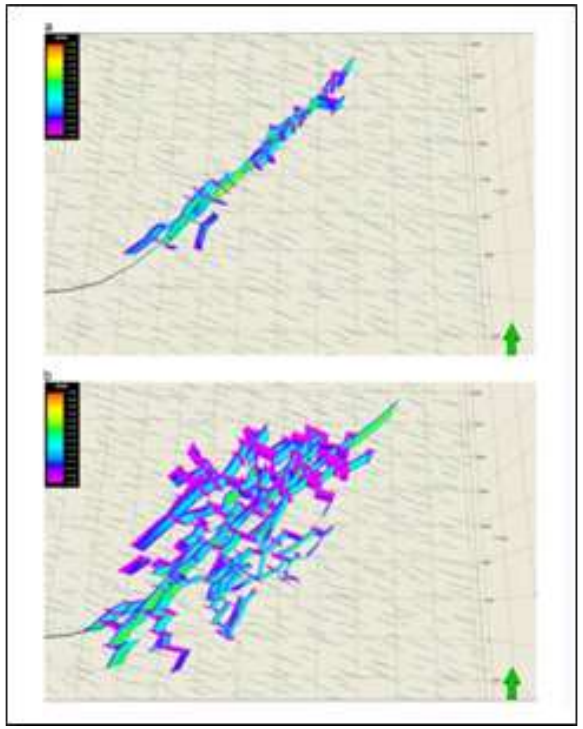
- Ideal work flow:
  - Characterize natural fracture network
  - Calibrate fracture properties from observed fracture network
  - Use calibrated model to design treatments in offset wells
- Practical application:
  - Match observed pressure, by modifying natural fracture network parameters
  - Result: “Garbage In = Garbage Out”
- Paradigm shift is **hampered by a rational limitation**: lack of data to populate geologically realistic models




Hydro-Frac interacts
With Natural Fractures

Fractures from Micro-Seismic Data

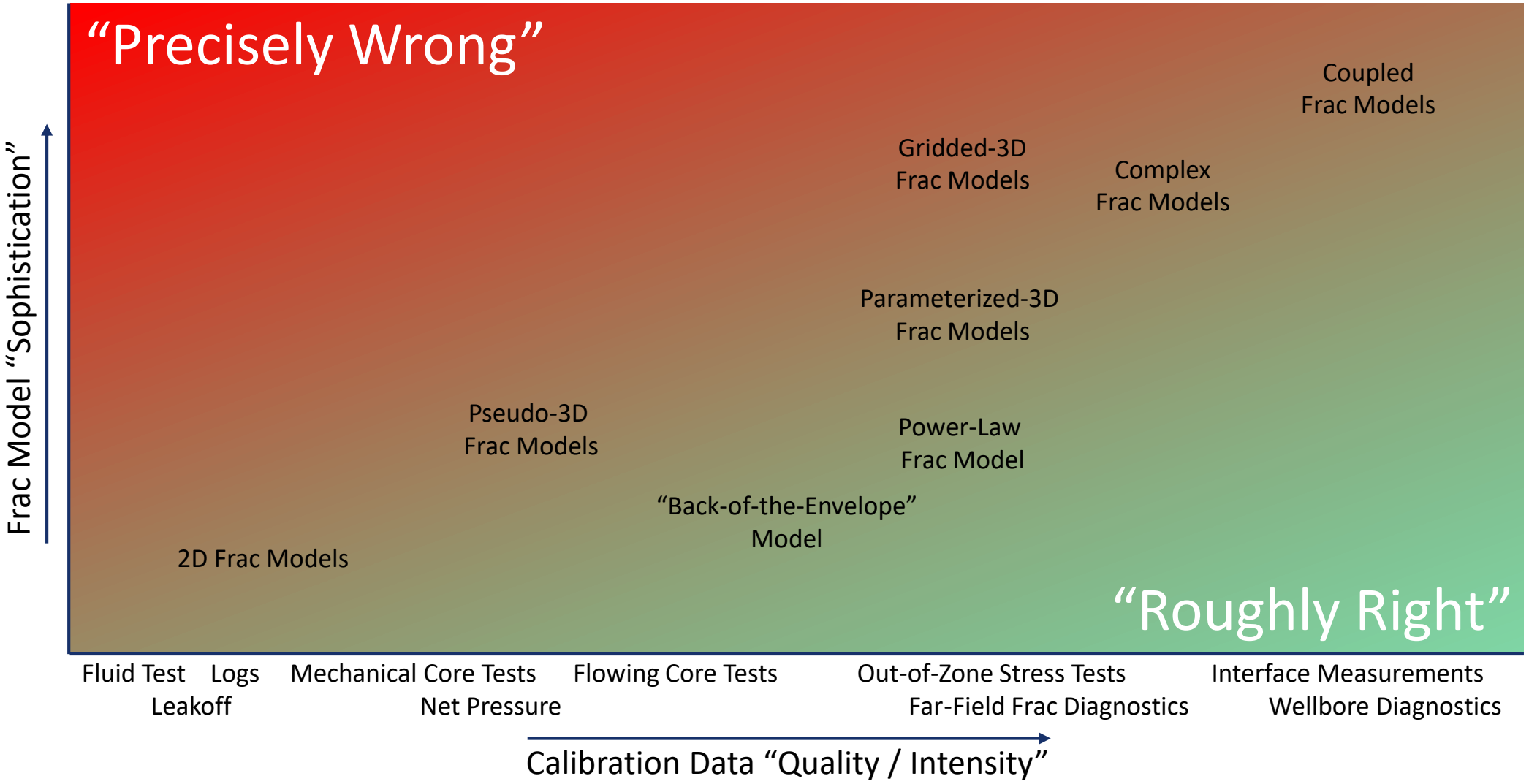


Sophisticated Fracture Networks
From Geological Characterization

# Balancing Frac Models with Diagnostics

"It is Better to be Roughly Right than Precisely Wrong", John Maynard Keynes



# Conclusions

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- Our industry has gone through a revolution, enabling economic frac designs in rocks with ~8 orders-of-magnitude change in permeability
- The role of calibration in fracture propagation models is critical for value-creation
  - Frac models have become practical tools through calibration
  - Calibration is straightforward and cost-effective
- “New” physical mechanisms reflect improved understanding
  - Multiple fractures, tip effects and composite layering effects
- Model sophistication should be matched with calibration quality
  - Planar frac model paradigm remains valid

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