Analyzing Performance of
North American Shale Gas Resources

2013 SPE - GCS - Reservoir Technology Forum

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NanoDarcy Rock Changes Everything

- **G&G:** Shale petrophysics, seismic, core analysis, microseismic fracture monitoring
- **Engineering:** “transient flow” lasts months or years versus hours or days
  - Months to years for fracs to see nearest neighbors
  - Years to Never for wells to see nearest offset wells
  - Frac spacing – reservoir dominated or completion dominated
- **What can you learn from early production (transient flow)?**
- **Fracturing:** how successful, how effective
- ***Must* quantify uncertainties:** to forecast, reserves bookings, optimal completion & well designs
- **Hard to keep up with the drill bit**

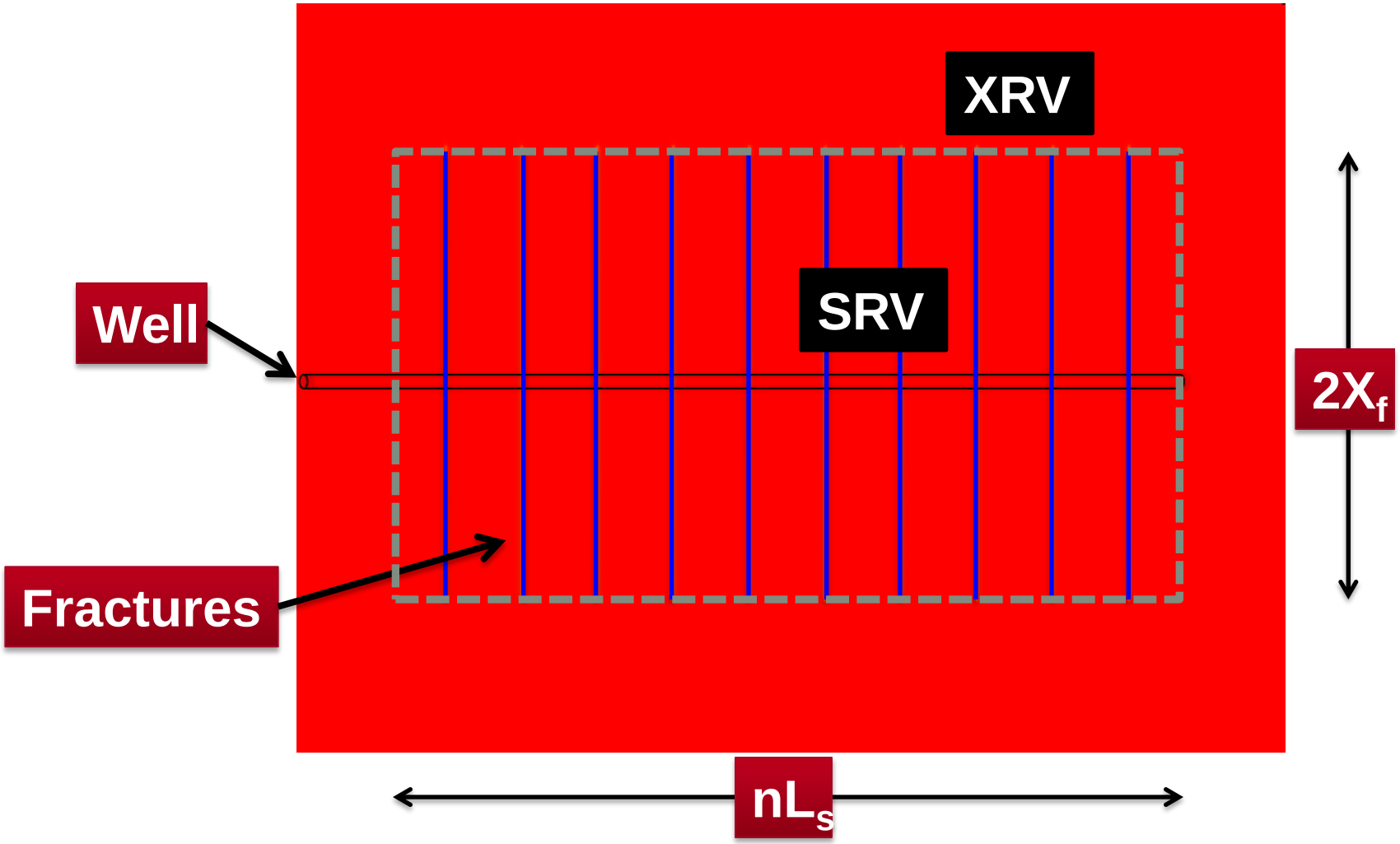
Shale Resource Drivers

- **Shale well performance depends on**
  - **OHIP**
  - **Effective permeability (k)**
  - **Effective fracture area (Af)**
  - **Average fracture spacing (Ls)**
  - **Drainage area (Ad)**

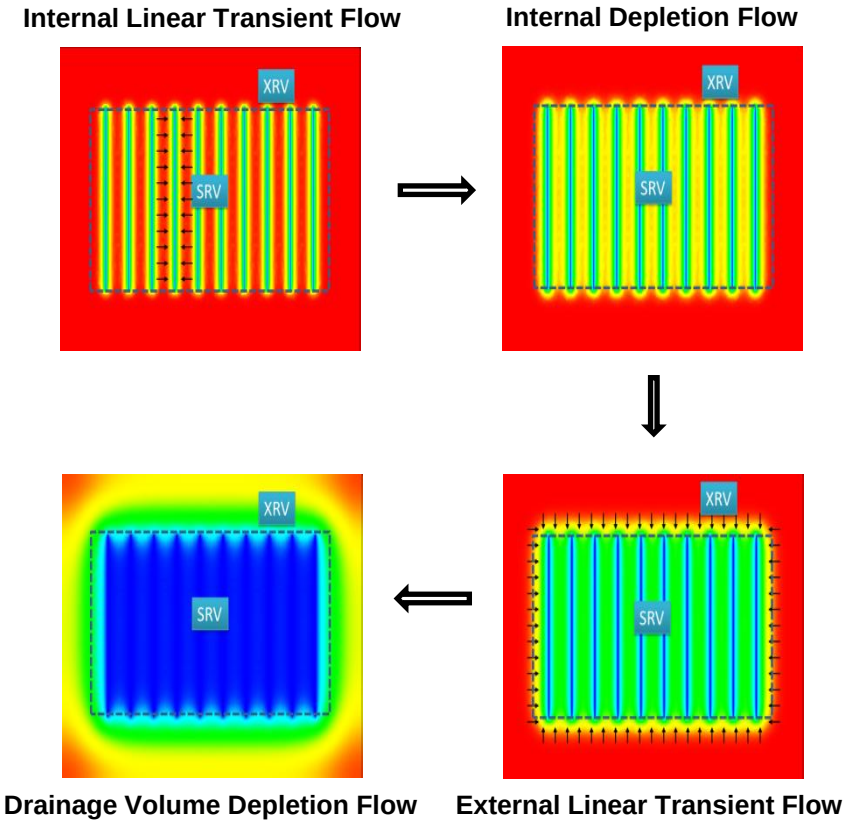
And is dictated by….

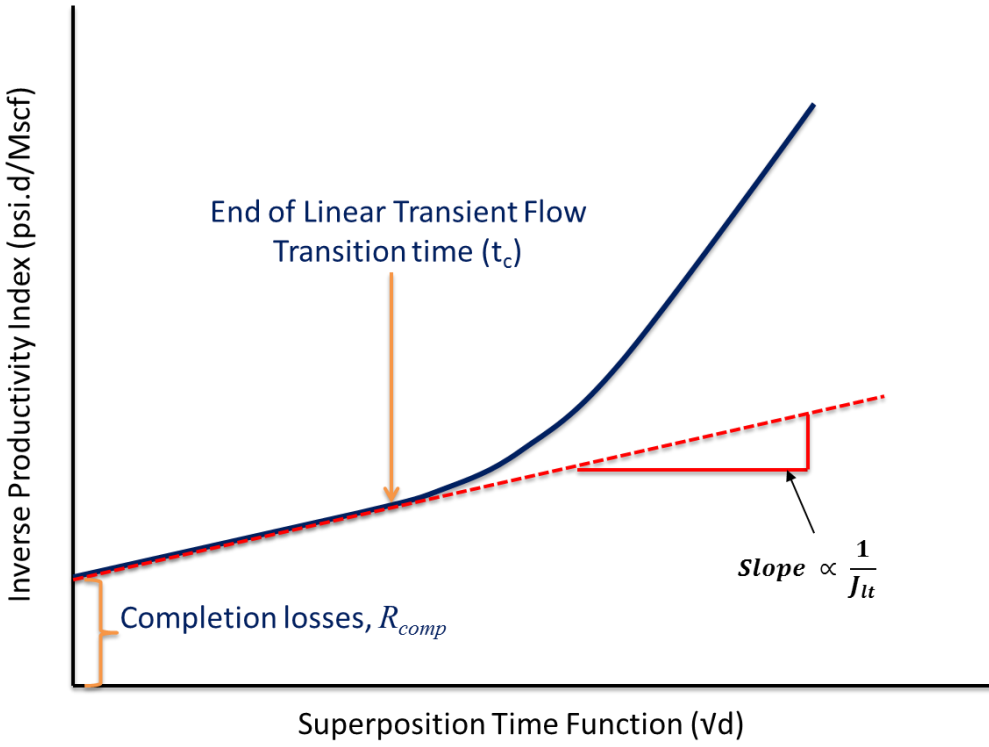
- **Nature**
  - **Reservoir Quality**
  - **Rock Quality**
- **Nurture**
  - **Well, completion design & efficiency**
  - **Facilities & production philosophy**
  - **Field development strategy**
- **Economic & Regulatory Constraints**

Shale Gas Well Schematic



Shale Well Performance Analysis

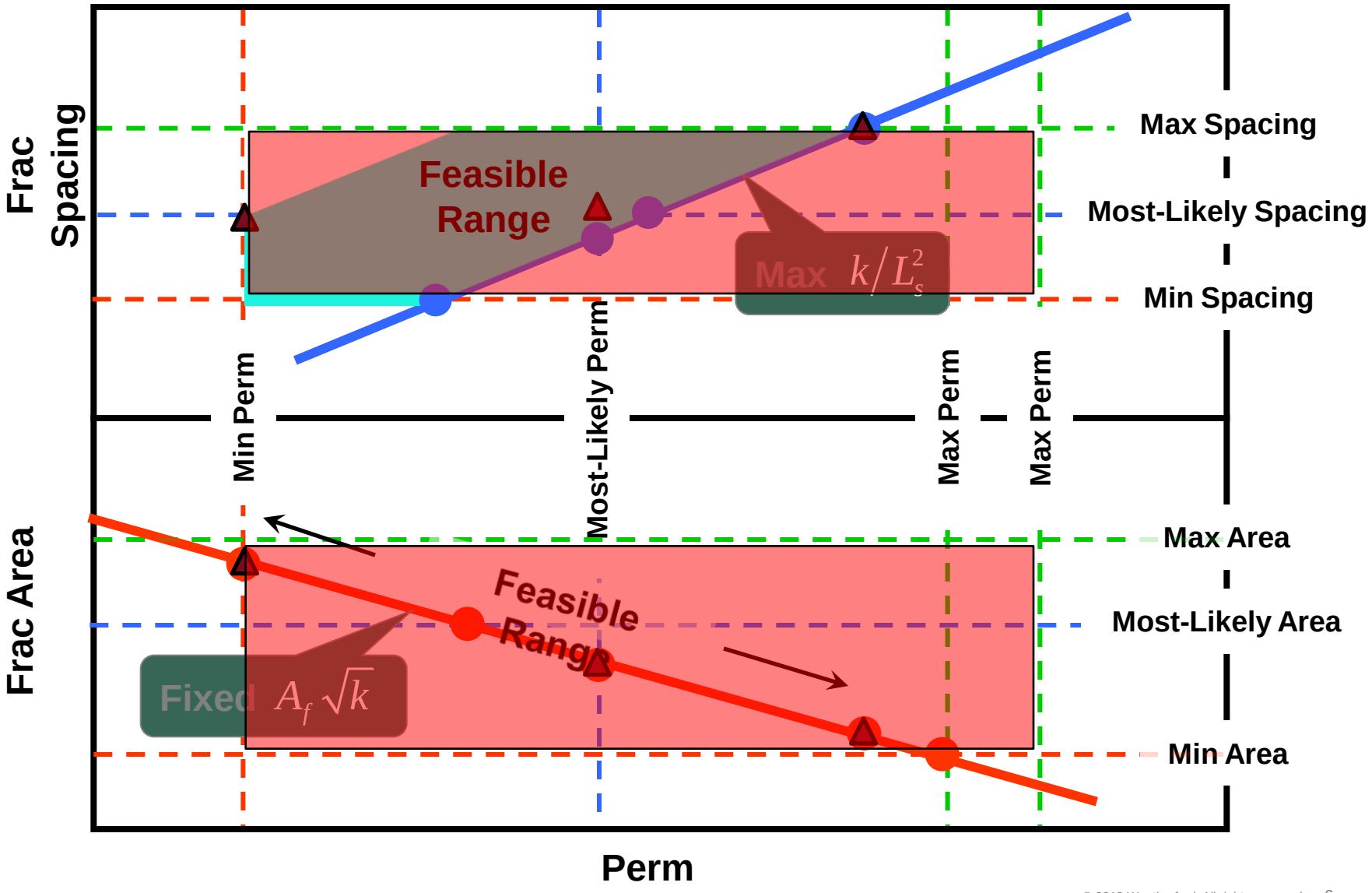




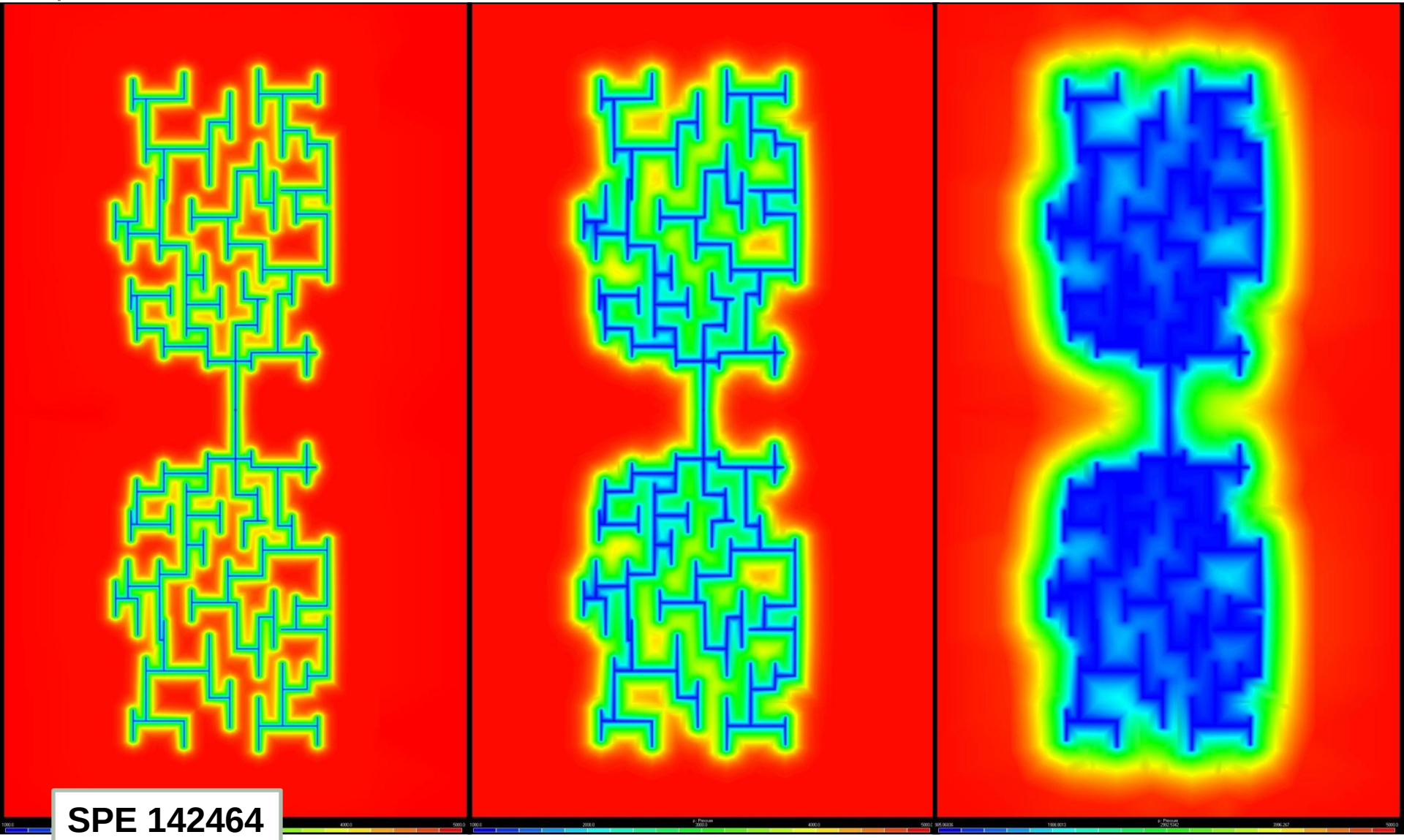
$$STF\left(t_n\right)=\frac{1}{q_n}\left[\Delta q_1\sqrt{t_{p,n}}+\sum_{j=2}^{n}\Delta q_j\sqrt{t_{p,n}-t_{p,j-1}}\right]$$

SPE 160271

Feasible Range Analysis



Simple or Complex Fractures



SPE 142464

Semi-Analytical Shale Model

SRV Dominated

$$J_{lt} \equiv \frac{A_f R_{n/g}}{B_{gi}} \sqrt{\frac{k_i \phi_i c_{ti}}{158.0206 \mu_{gi}}} \frac{\text{Mscf}}{\text{psi} \cdot \text{d}^{1/2}}$$

Internal Linear Transient Productivity Index

$$J_{dep} \equiv \frac{1}{158.0206} \frac{k_i R_{n/g} A_f \sqrt{\sigma}}{B_{gi} \mu_{gi}} \frac{\text{Mscf}}{\text{psi} \cdot \text{d}}$$

Internal Depletion Flow Productivity Index

XRV Dominated

External Linear Transient Productivity Index

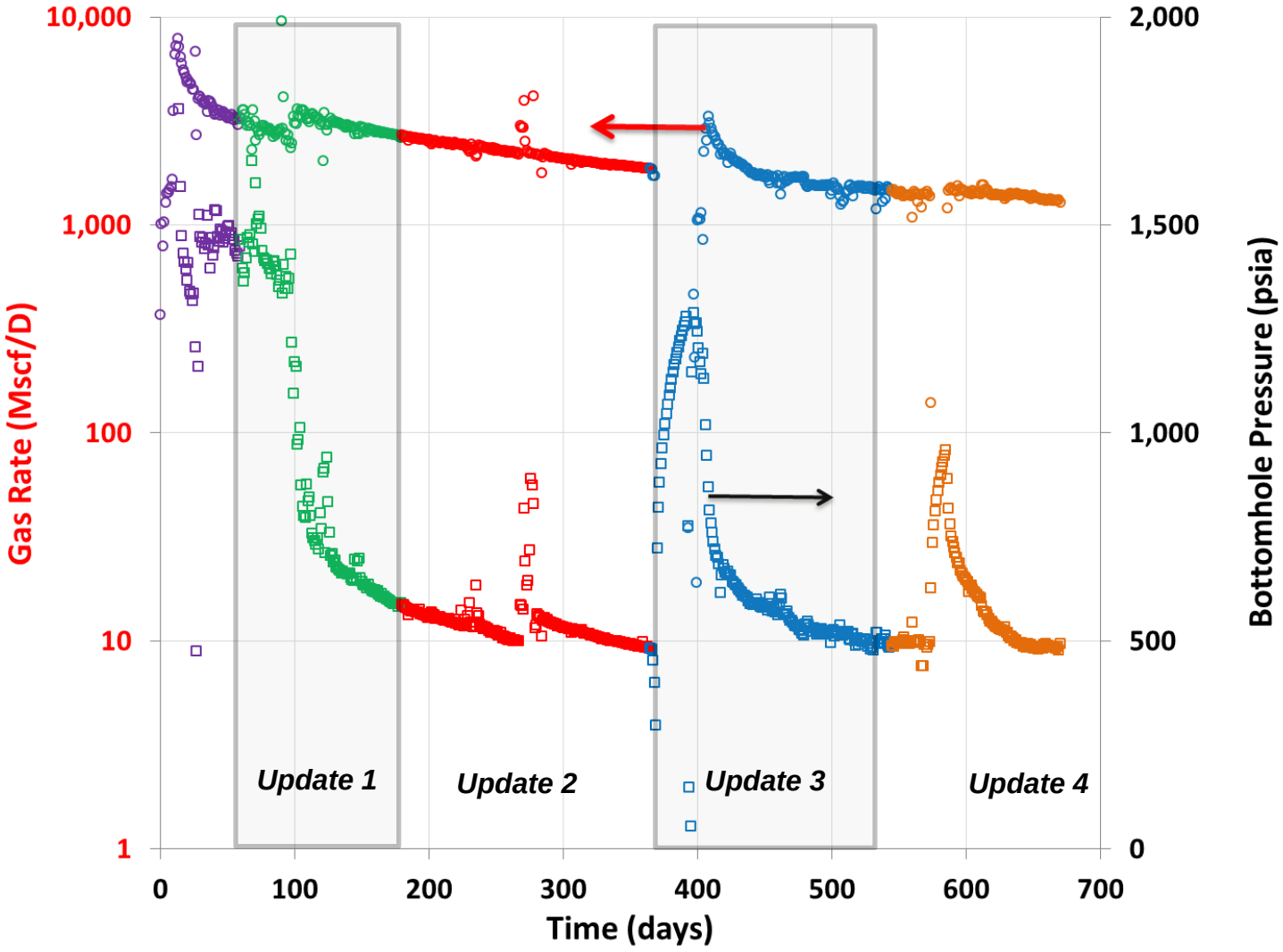
$$J_{lt,ex} \equiv \frac{A_{SR} R_{n/g}}{B_{gi}} \sqrt{\frac{k_i \phi_i c_t}{158.0206 \mu_{gi}}} \frac{\text{Mscf}}{\text{psi} \cdot \text{d}^{1/2}}$$

External Depletion Flow Productivity Index

$$J_{dep,ex} \equiv \frac{1}{158.0206} \frac{k_i R_{n/g} A_{SR}}{B_{gi} \mu_{gi} L_d} \frac{\text{Mscf}}{\text{psi} \cdot \text{d}}$$

SPE 139097

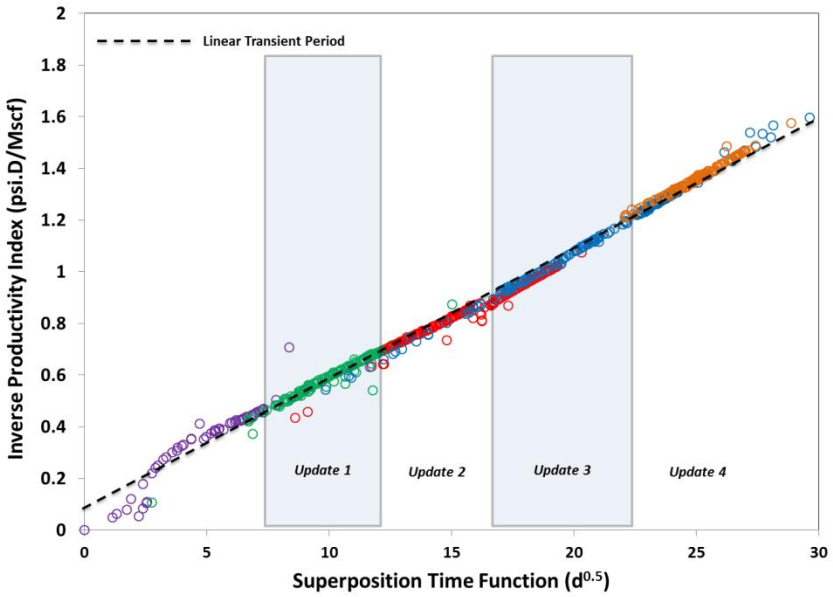
Example Well



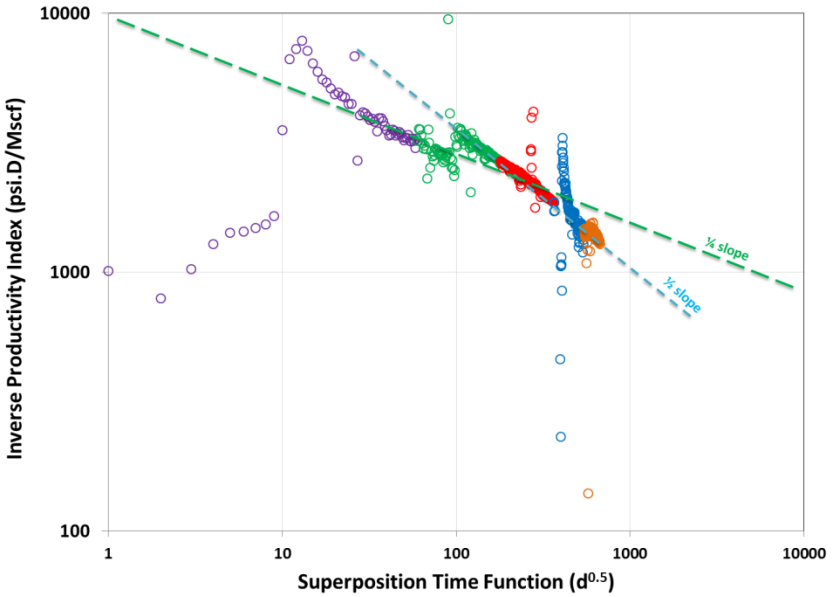
SPE 162821

Diagnostic Plots

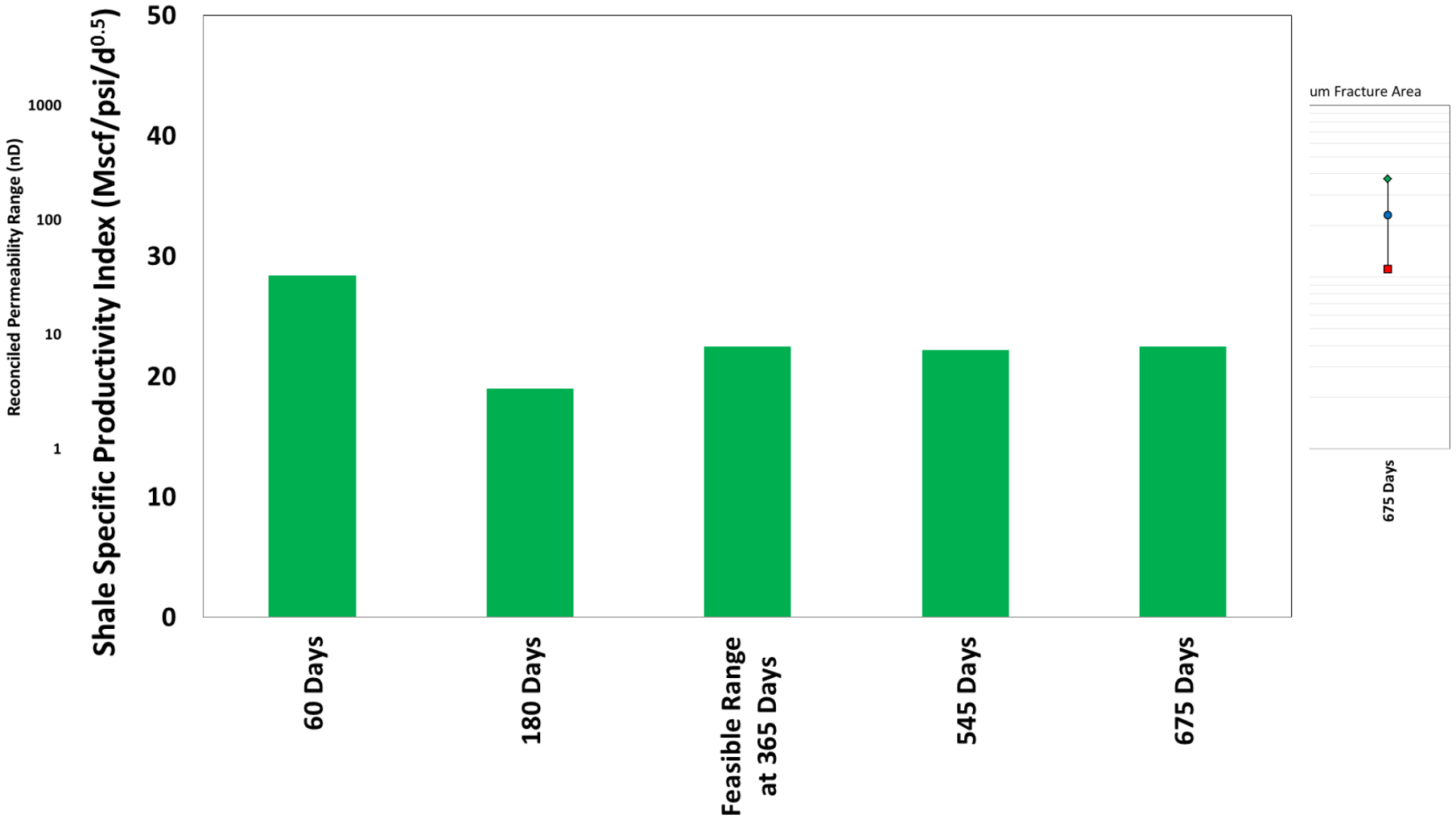
Linear Flow Diagnostic Plot



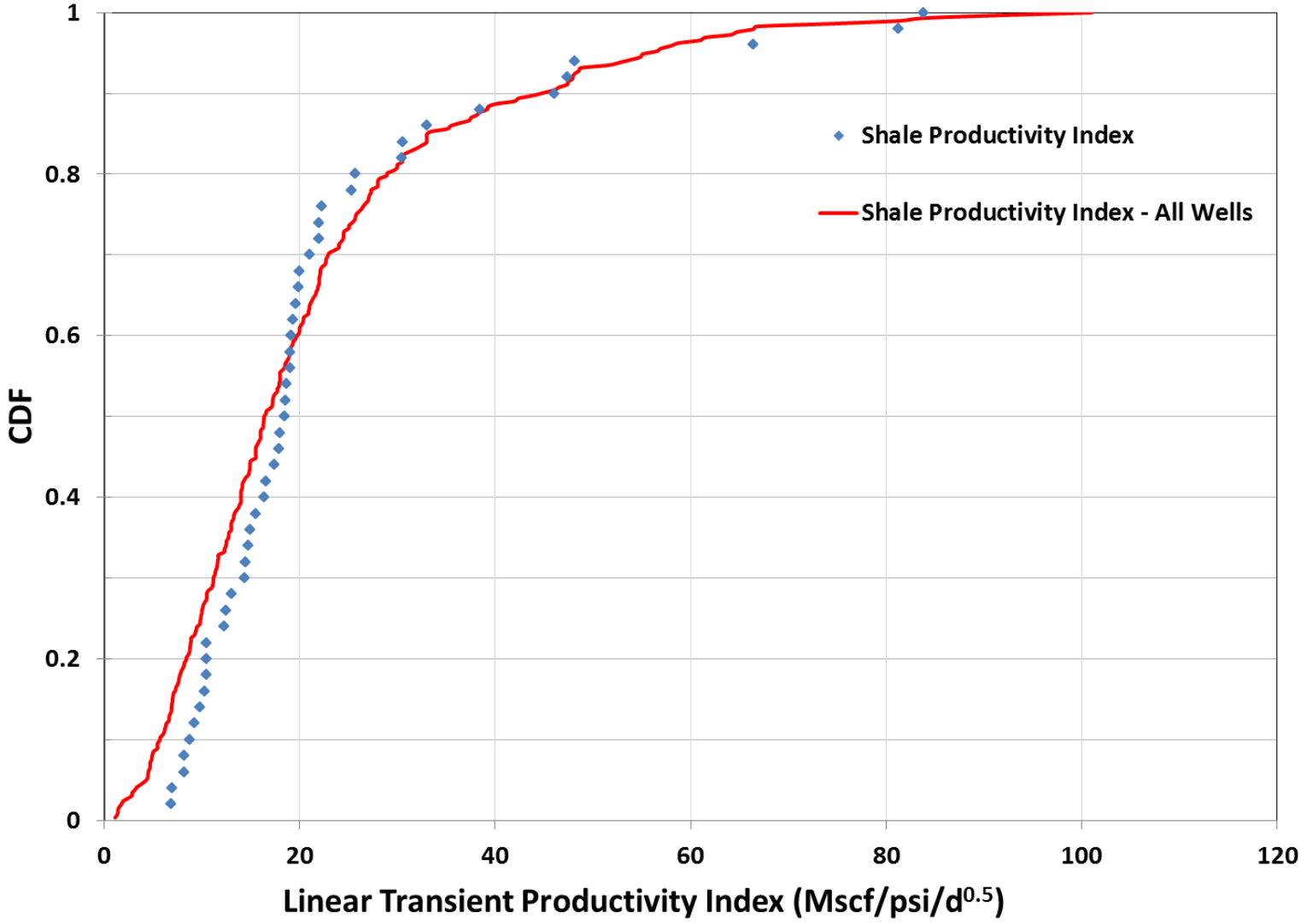
Log-Log Diagnostic Plot



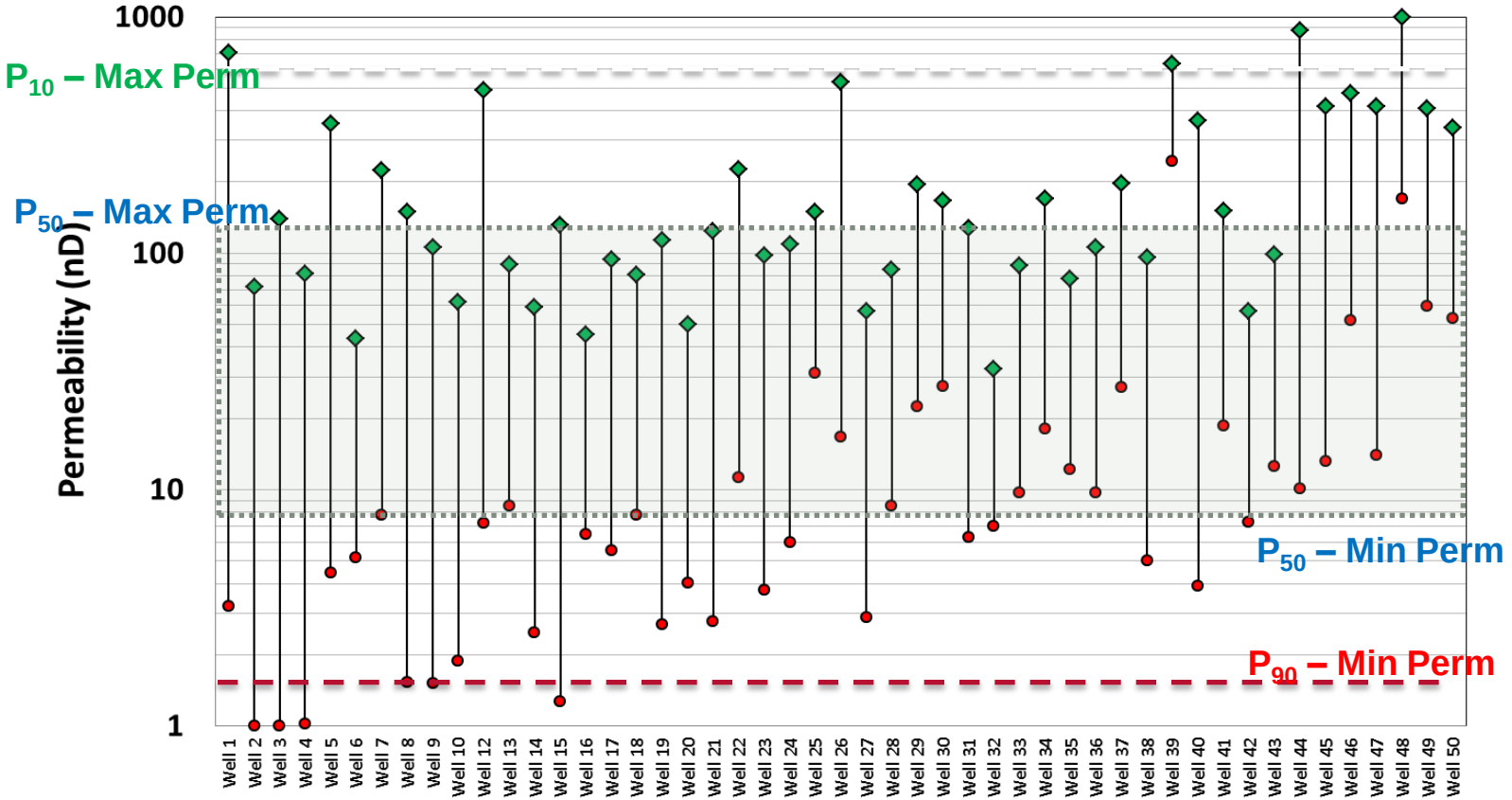
Asset Progression



Benchmarking Well Performance



Estimated Permeability



Better Wells

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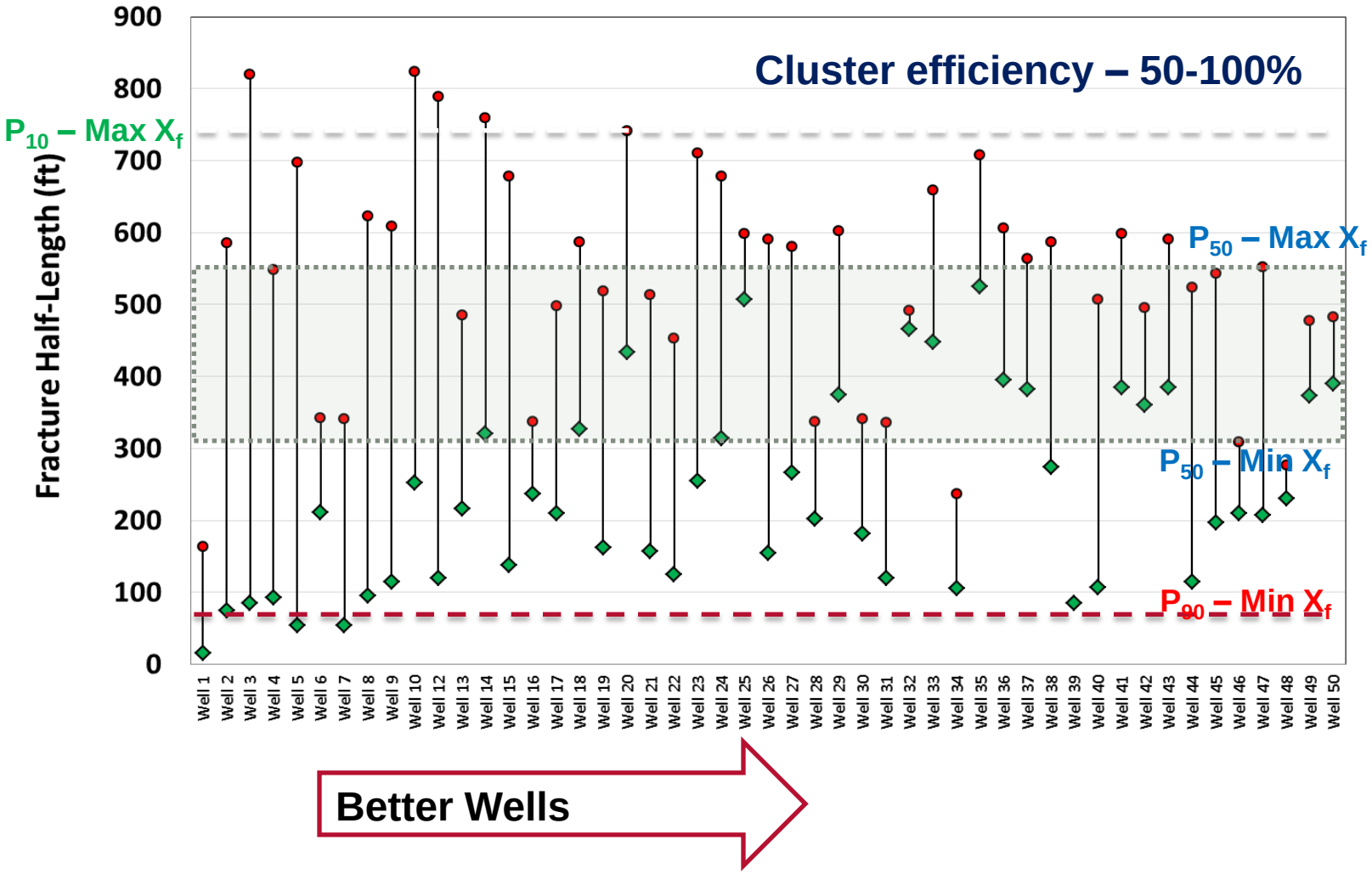
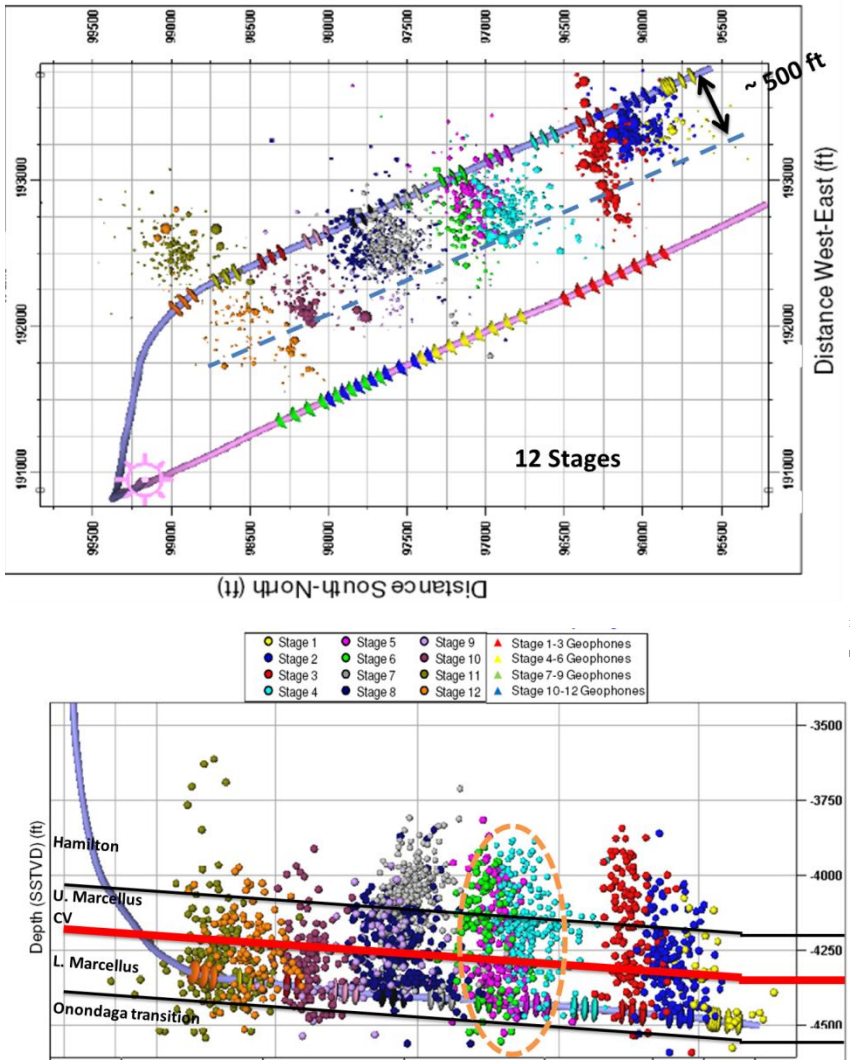
Interpreted Fracture xf

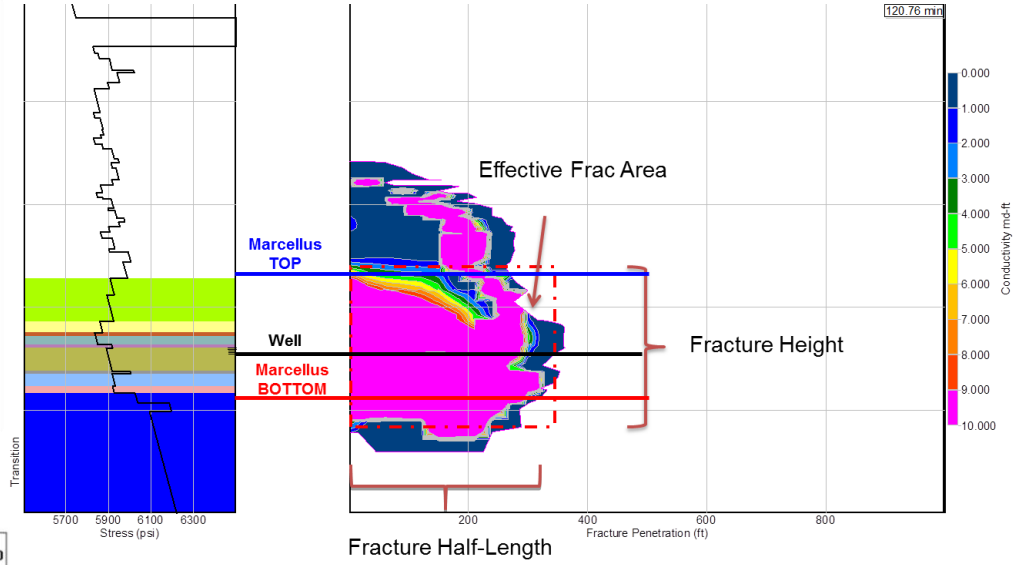


Reconcile – Completion

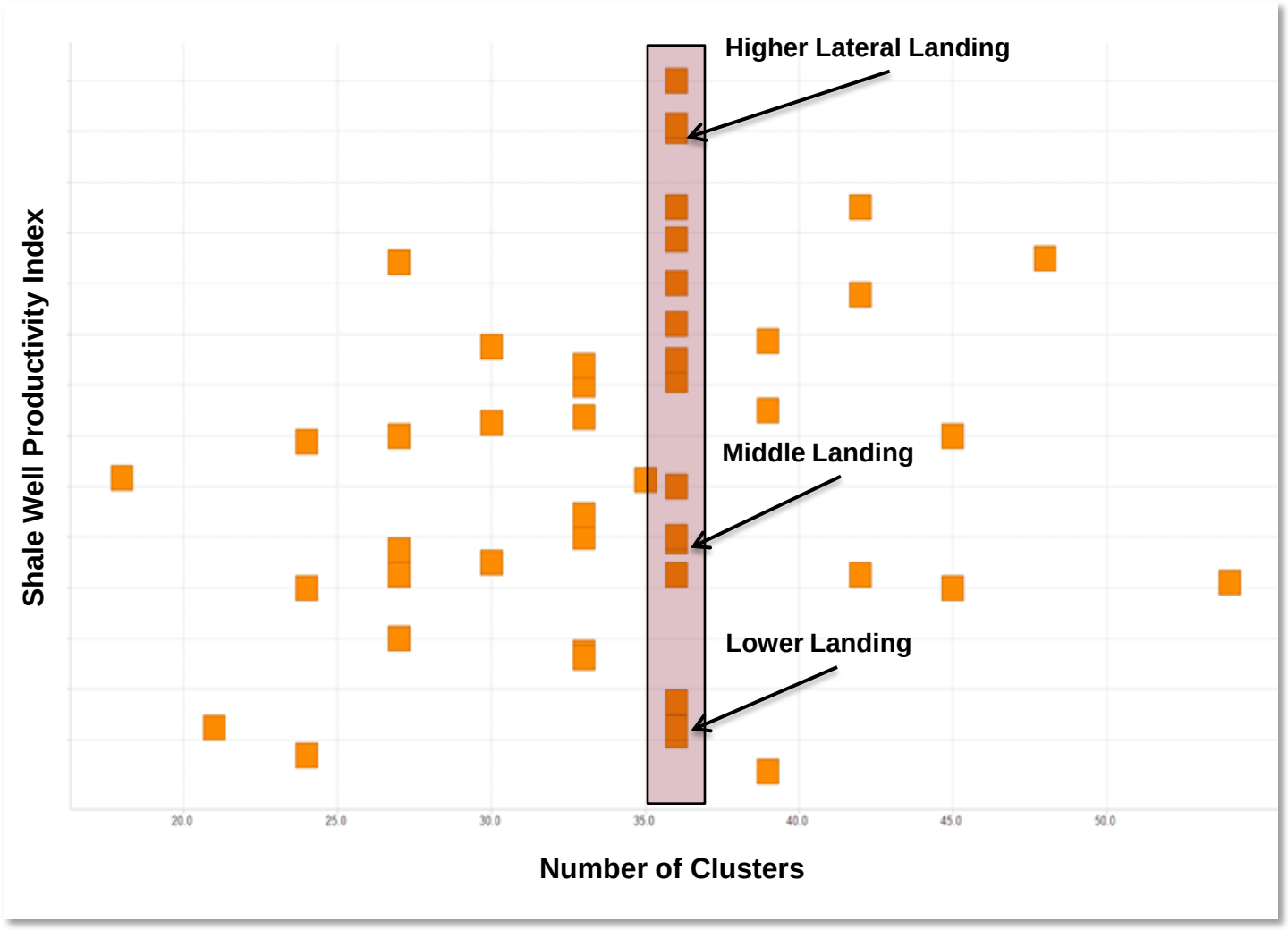
Microseismic



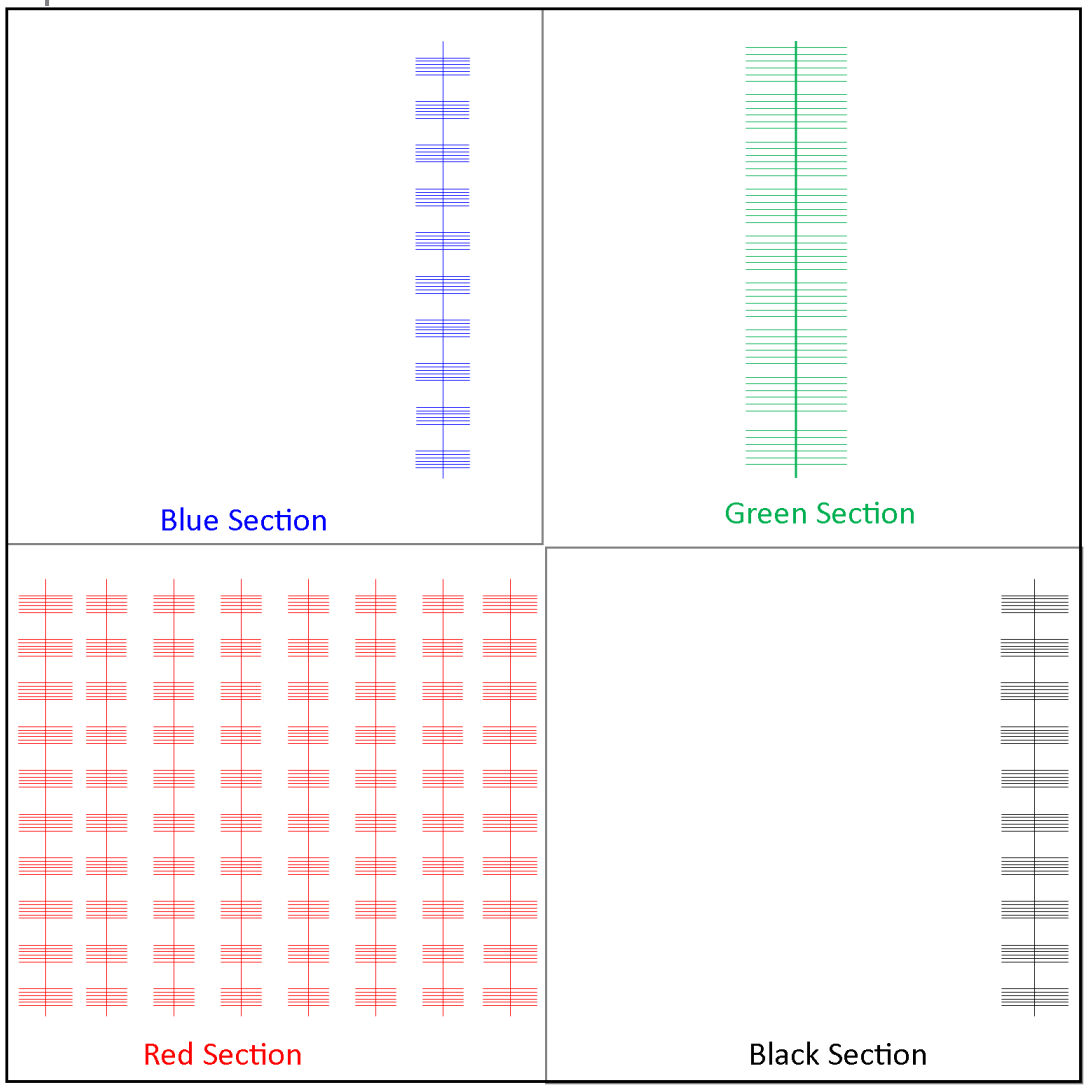
Geomechanical Model



Reconcile – Drilling



Woodford Field Development Planning

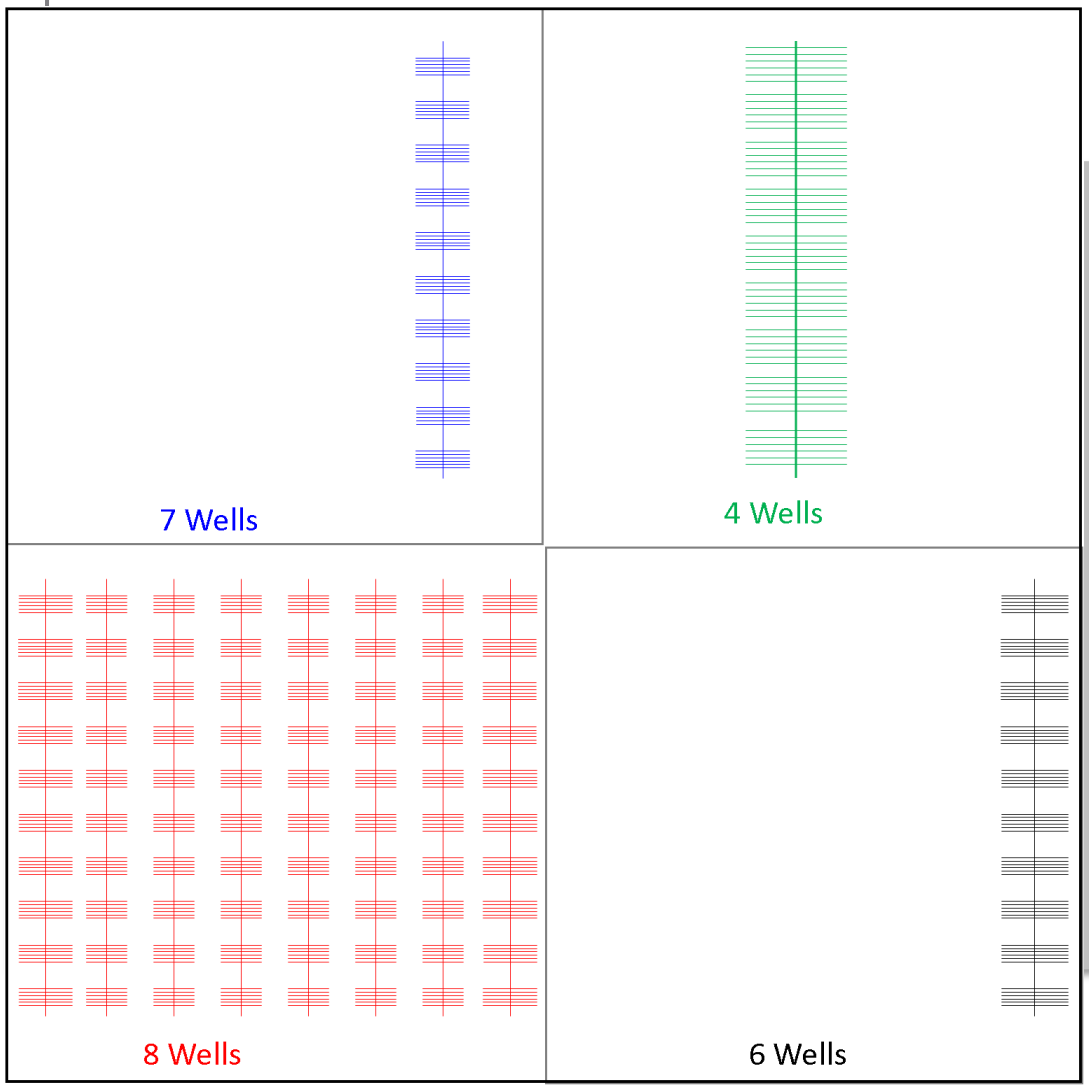


Red Section

- Inner wells have 20% less productivity
  - Inner wells drive economics
  - Outer wells suggest larger spacing

% More Proppant	% Better Productivity	% Higher $Rate_{90}$
80	40	55
100	60	80
125	90	135

Woodford Field Development Planning



- 8 wells initially planned per section reduced to 4-6 wells
- Increased completion cost offset by higher productivity wells
- Significantly higher NPV
- Planning cycle: Multiple months became <3 weeks

Review

- What are the key reservoir & completion properties impacting Shale well performance

  a) Reservoir permeability

  b) Fracture Area

  c) Hydrocarbon in place

  d) All of above

