Applied Geoscience Conference

Digital Rock Simulation: A Novel Approach for Characterization of Perforation Tunnel Damage & Productivity

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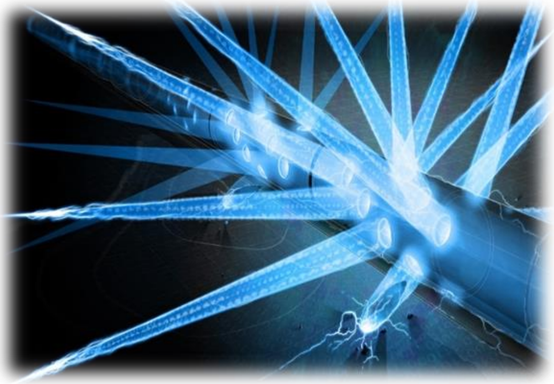
Baker Hughes

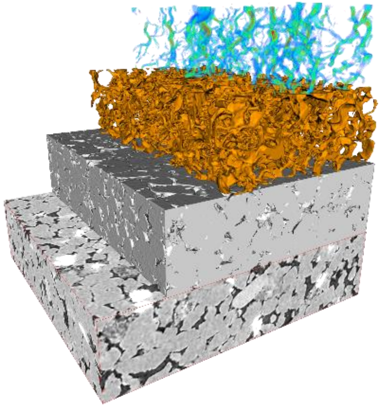
SIMULIA

Presentation Outline

- Introduction
- Objectives
- Perforation Flow Laboratory
- Workflow
- Damage Characterization
- Applications

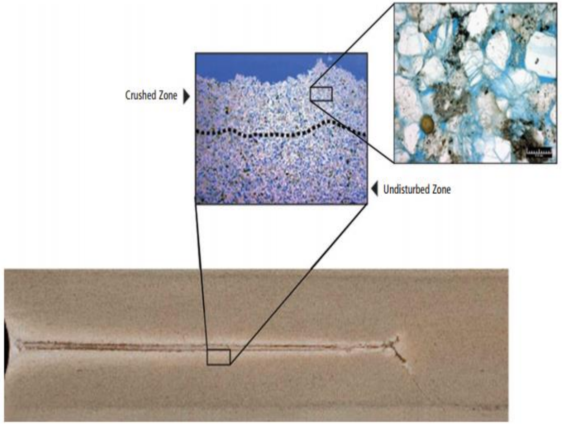
    Productivity Analysis





Introduction

- Perforating (using shaped charges) is widely used to establish hydraulic communication between the formation and wellbore.
- "Clean" perforation tunnels can efficiently transport hydrocarbons. Dynamics of the perforating event inevitably compresses the formation, resulting in "crushed" or "damaged" rock surrounding the tunnel.
- Critical to understand the physical characteristics of the damaged zone
  - ✓ Designing/Optimizing perforating jobs
  - ✓ Numerical modeling of perforating events
- Extremely small length scales and arbitrary surface make it impractical for laboratory or traditional modeling methods to quantify the damaged zone.
- Explore the applicability of ***Digital Rock.***



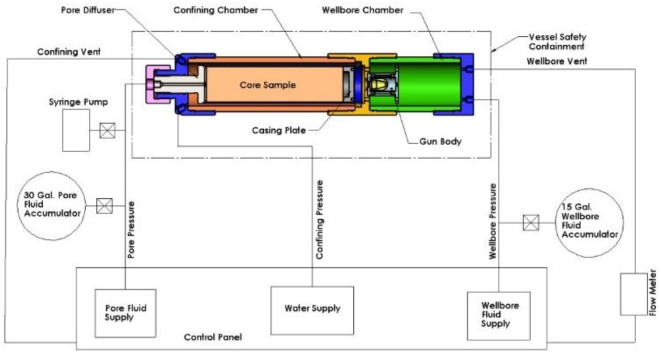
Objectives

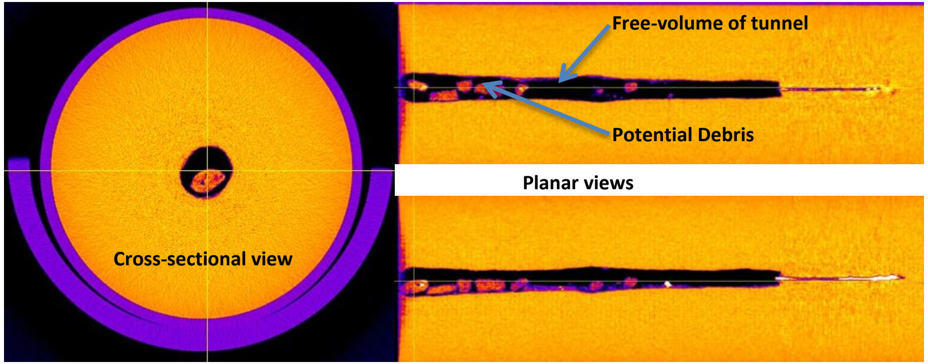
- Application of Digital Rock methodology to characterize and quantify perforation damage in rocks
- Multi-scale simulation approach to accurately predict productivity in perforated rocks
- Multiscale reservoir physics and data interpretation

Perforation Flow Laboratory

The flow laboratory provides the capabilities to:

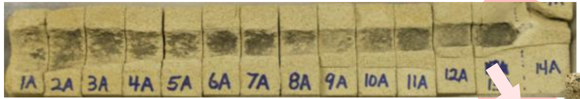
- Study and qualify the performance of different perforating systems in formation rock at reservoir conditions.
- Study the influence of various factors on well productivity.
- Integrate this knowledge to select the optimal perforating system and clean up strategy for improved productivity.

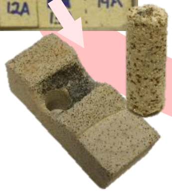


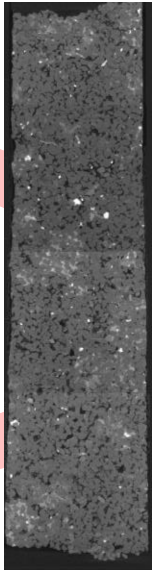


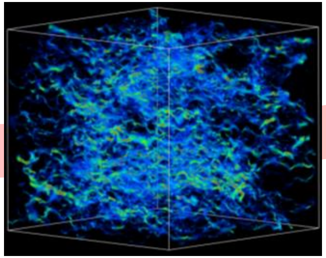
Integrated Experimental / Numerical Workflow

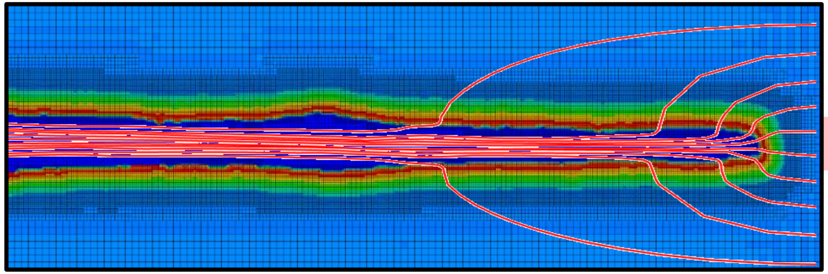
- API RP-19B Section-IV test
- Extract plugs
- CT evaluation
- Pore Space Analysis
- Lattice Boltzmann Simulation
- Permeability Evaluation
- Production Model





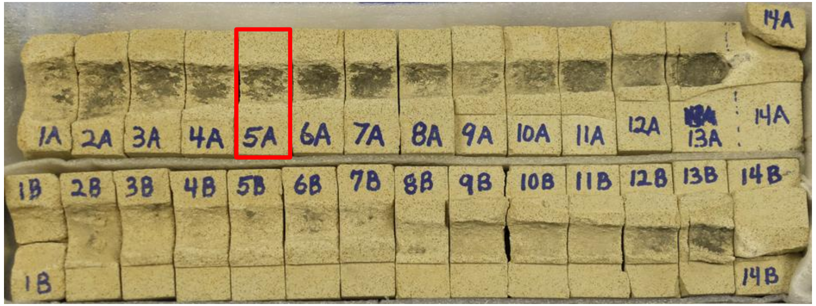


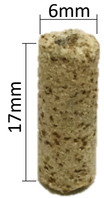


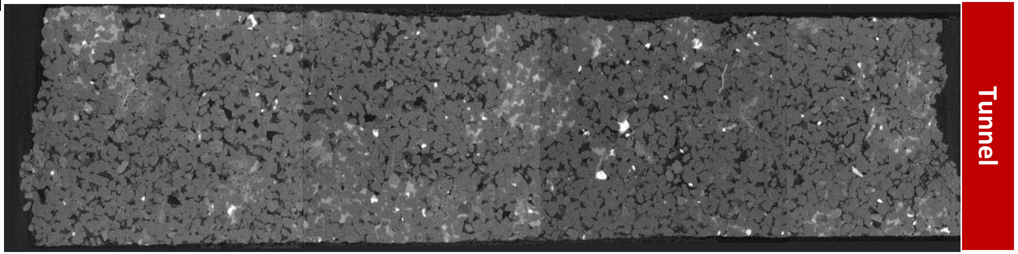


Characterizing Damage: Experiments

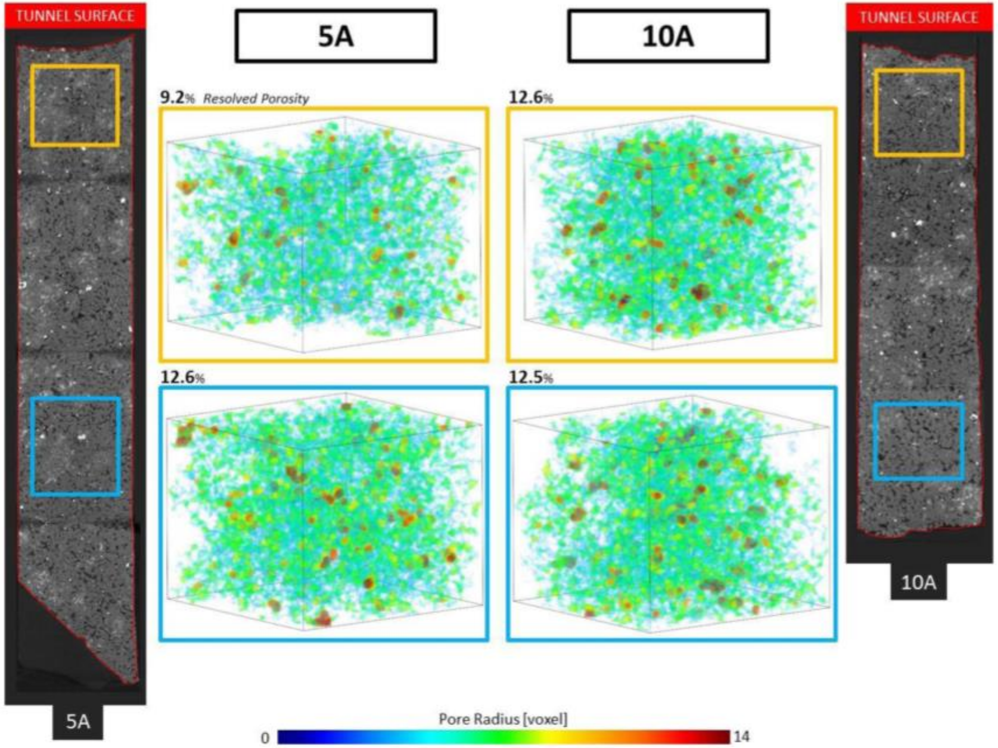
- API RP19-B Section IV test performed on Berea sandstone core
- Perforated test section cut into sub-sections
- Cylindrical plugs drilled from multiple sub-sections and pore scale microCT imaging performed
- Resulting scans provide detailed pore space geometry for flow simulation analyses

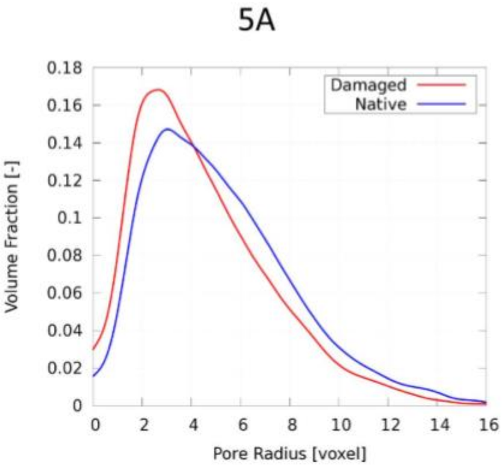






Characterizing Damage: Digital Rock





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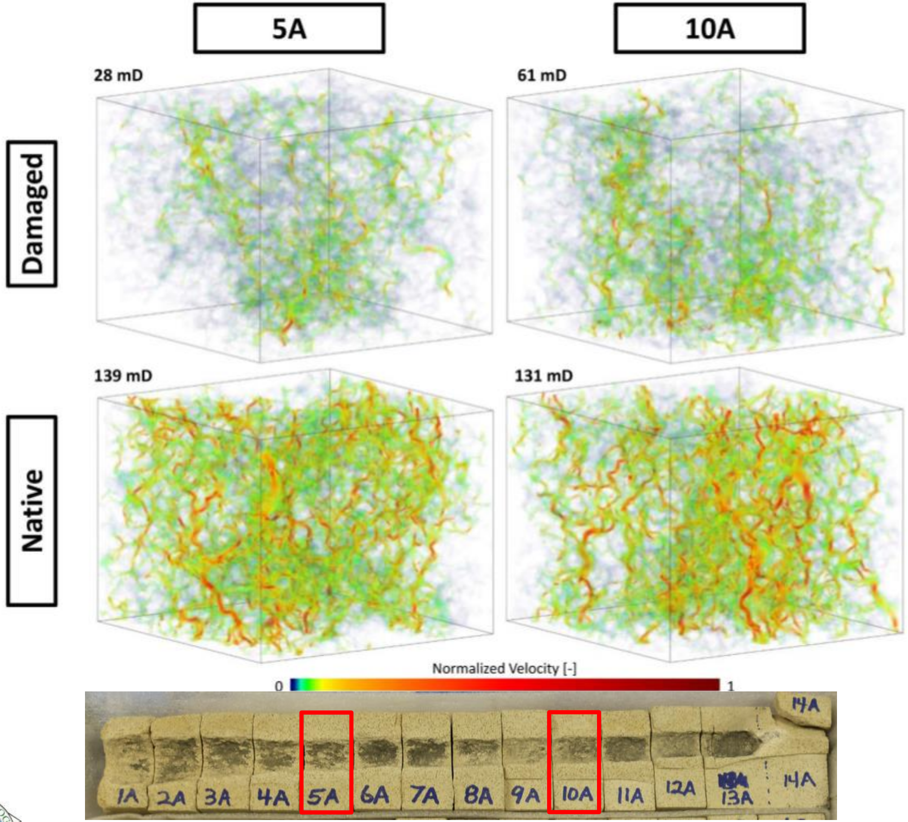
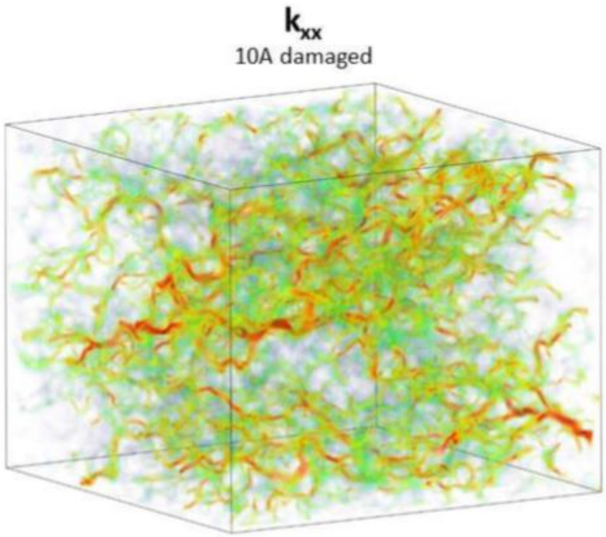
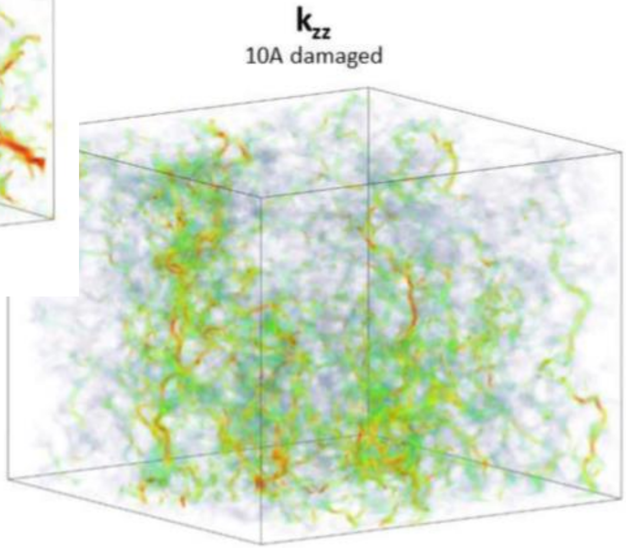


- Permeability determined from lattice-Boltzmann method simulations
- Permeability increases with distance from tunnel
- 5x permeability change from tunnel surface to native rock

Characterizing Damage: Digital Rock

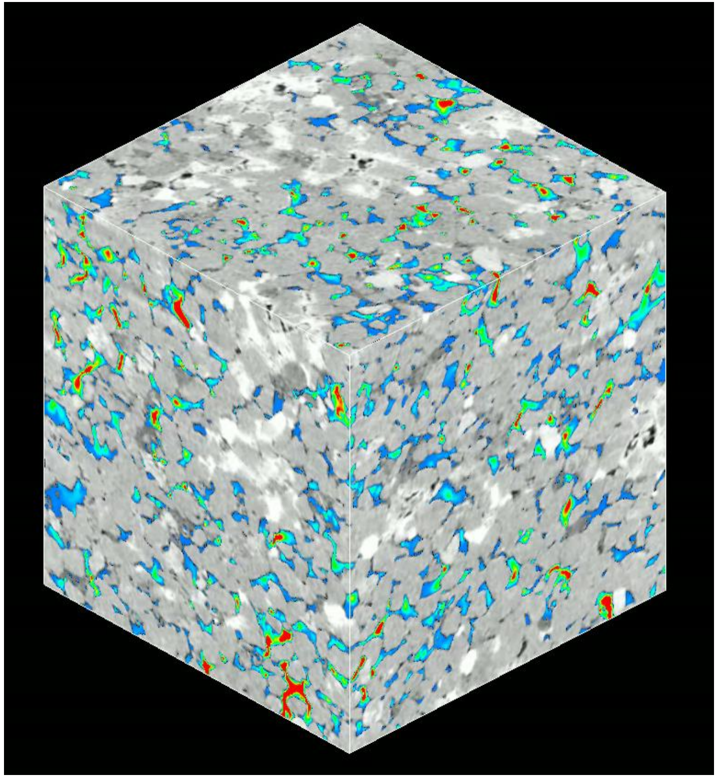




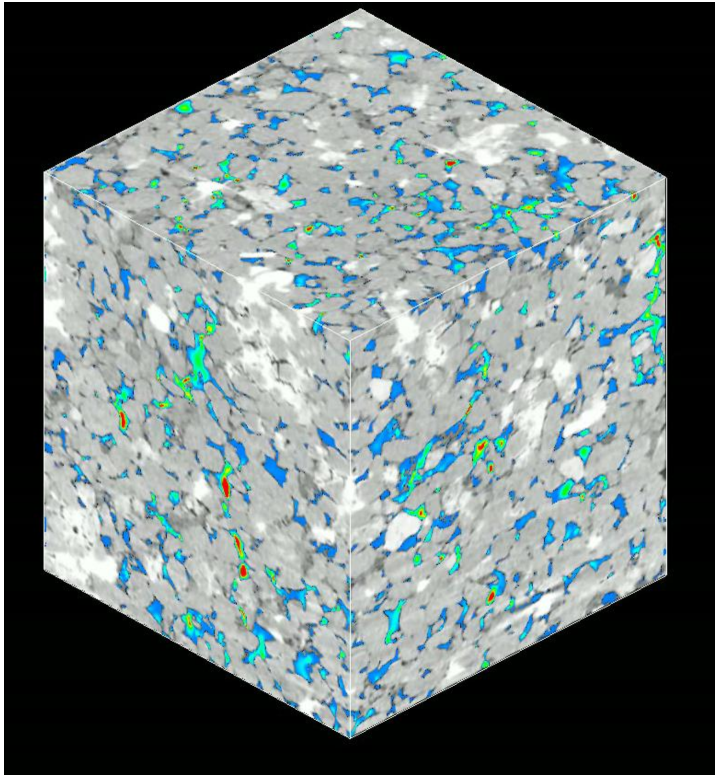
- Cross-flow permeability
- Effect of perforation process to the anisotropy of rock properties
- Significant anisotropy observed only for the damaged zone.

Characterizing Damage: Digital Rock

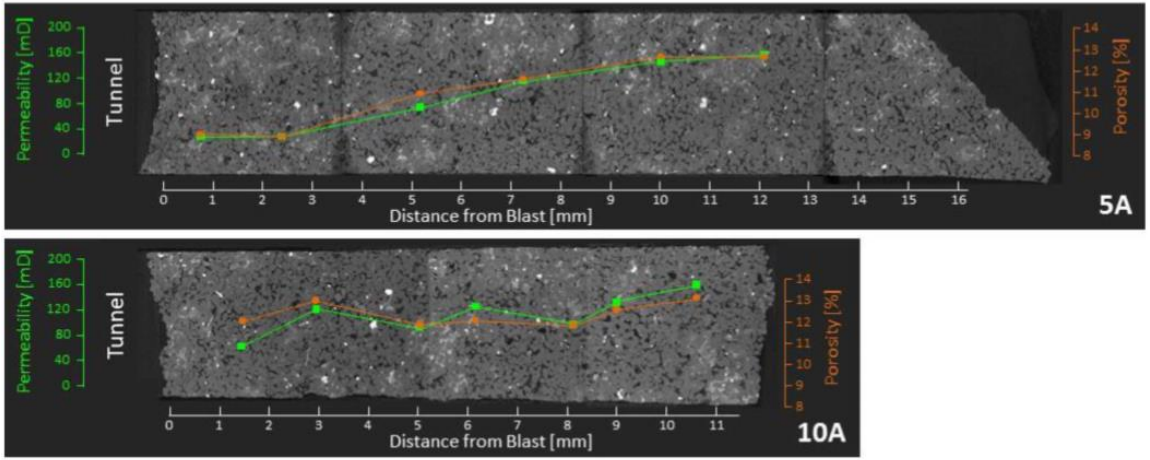
Native



Damaged



Characterizing Damage: Quantitative Profiles

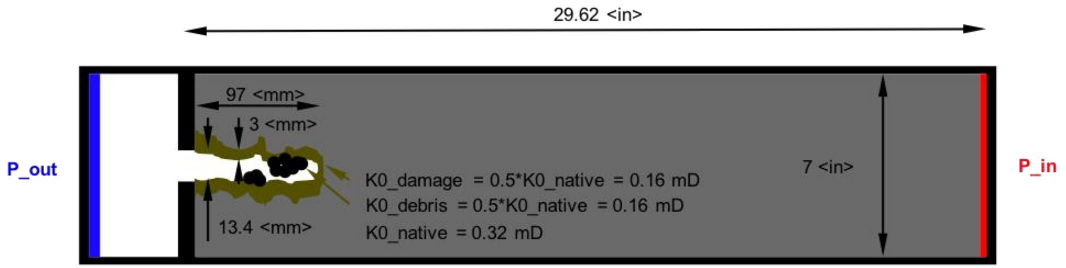


- **5A plug**
  - Damaged zone thickness ~ 11mm
  - Permeability varies from 40mD to 160mD
- **10A plug**
  - Damaged zone thickness ~ 10mm
  - Permeability varies from 60mD to 150mD
- **Capability of Digital Rock to provide localized porosity/permeability information clearly demonstrated.**

Applications: Productivity Analysis

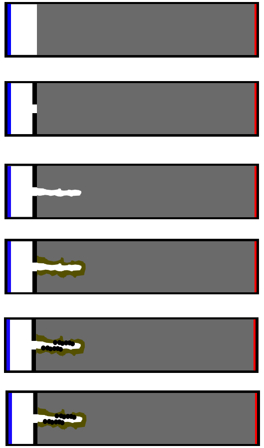
- Input parameters: Core length, core diameter, true geometry of the tunnel (with and without debris, as used in lab test), damage zone thickness, fluid viscosity, porosity, permeability.

- Lattice Boltzmann Flow Solver with a Darcy formulation for the porous media



Applications: Productivity Analysis

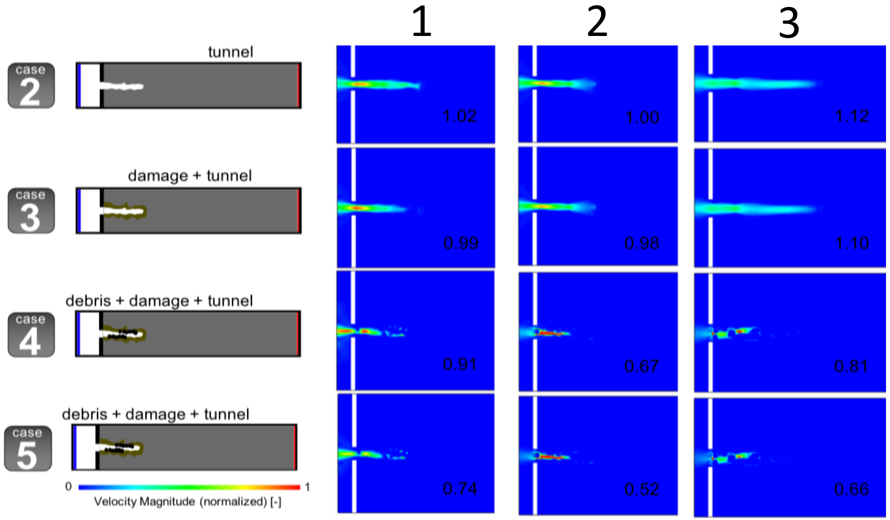
Case Layout		Productivity	Productivity Ratio
pre-shot	case 0	6.29 cc/min	1
casing only	case 1	3.15 cc/min	0.50
tunnel	case 2	6.42 cc/min	1.02
damage + tunnel $K_{0,damage} = 0.5 * K_{0,native}$	case 3	6.26 cc/min	0.99
debris + damage + tunnel $K_{0,debris} = K_{0,damage} = 0.5 * K_{0,native}$	case 4	5.72 cc/min	0.91
debris + damage + tunnel $K_{0,debris} = K_{0,damage} = 0.1 * K_{0,native}$	case 5	4.67 cc/min	0.74

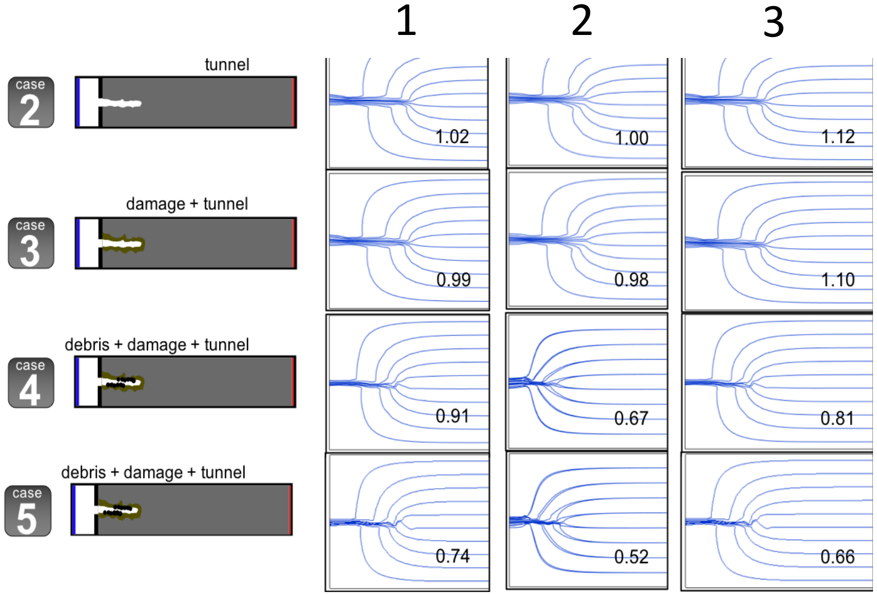


Competing effects of various factors can be easily studied around true perforation geometries

- The casing adds significant resistance to flow, productivity ratio, PR=0.50 (casing only).
- Adding the tunnel leads to slightly higher productivity compared to pre-shot productivity, PR=1.02 (tunnel).
- Damage at 50%/3mm did not significantly reduce productivity, PR=0.99 (tunnel+damage).
- Debris reduces productivity by a noticeable amount, PR=0.91 (tunnel+damage+debris, 50%/3mm).
- Reducing permeability of the debris and damage zone to 10% has a large effect, resulting in PR=0.74 (tunnel+damage+debris, 10%/3mm).

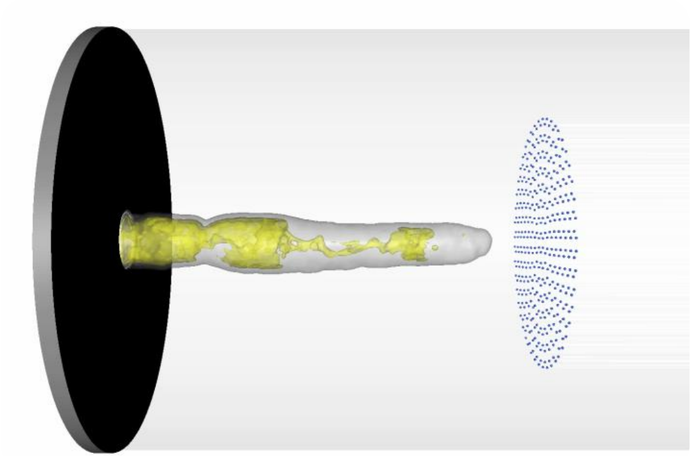
Applications: Productivity Analysis

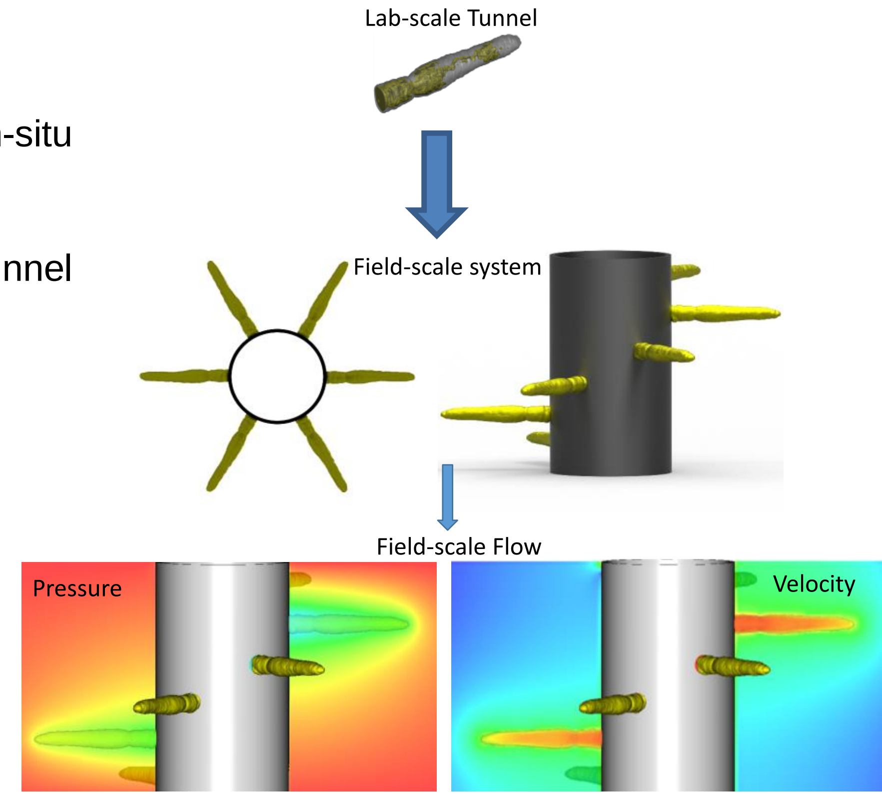




Applications: Upscaling Productivity Analysis

- Upscale single perforation tunnels (from an in-situ laboratory test) into a system level model.
- Well-scale prediction of clean-up mechanisms, tunnel interference, overall productivity etc.





Conclusions

- ***Digital rock approach*** for modeling perforation tunnel damage is demonstrated.
- Pore scale simulations are important to quantify the damage zone permeability
- Resulting damage (porosity/permeability) characterization allows detailed perforation productivity analysis
- Other Applications
  - Developing multi-scale / fast-physics methods for reservoir asset development
  - Applying Digital Rock in Well-Completions design and optimization.

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Acknowledgements

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QUESTIONS ?