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MENAPS 2016

Middle East and North Africa Perforating Symposium

MUSCAT, OMAN

Multi-Scale Modeling for Predicting the Productivity of Perforated Completions

MENAPS 16-06

NOV 13TH, 2016

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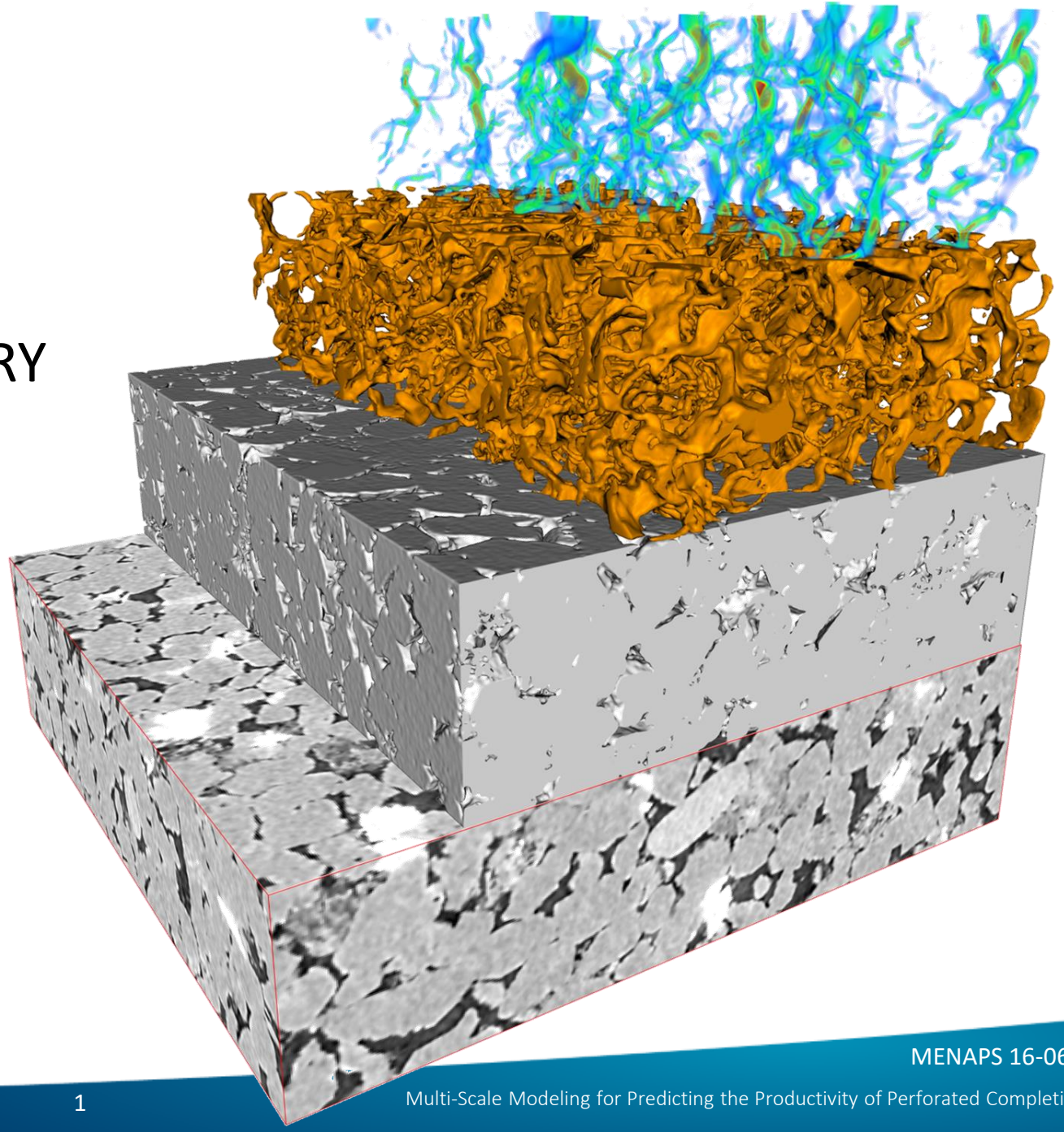
- PERFORATION FLOW LABORATORY
- WORKFLOW OVERVIEW
- DAMAGE CHARACTERIZATION
- PRODUCTIVITY ANALYSIS
- CONCLUSIONS



INTRODUCTION

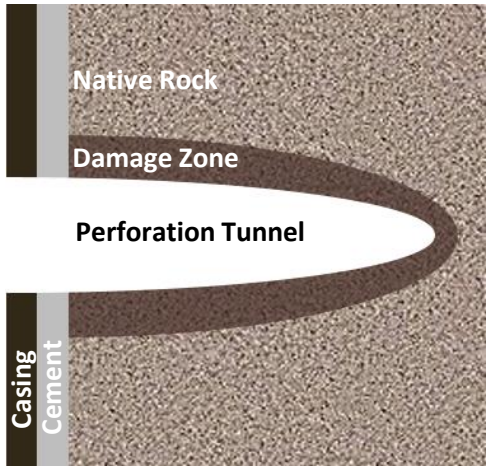
- Perforating (using shaped charges) is widely used to establish hydraulic communication between the formation and wellbore.

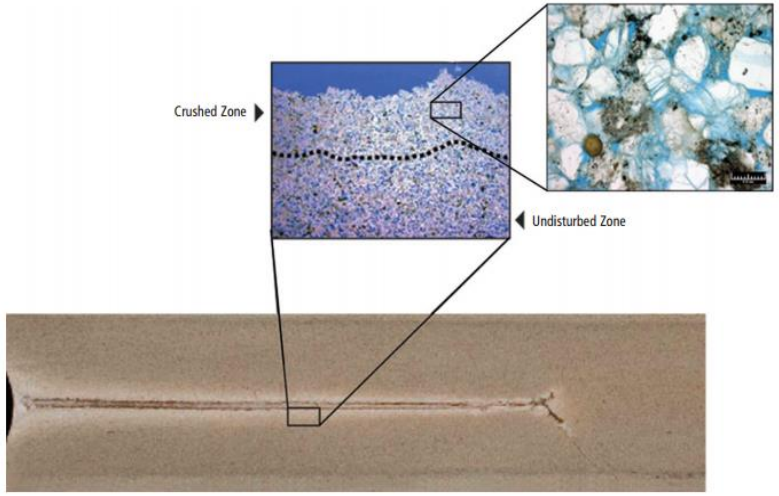
- “Clean” perforation tunnels can efficiently transport hydrocarbons. Dynamics of the perforating event inevitably compresses the formation, resulting in “crushed” or “damaged” rock surrounding the tunnel.

- Critical to understand the physical characteristics of the damaged zone
  - ✓ Designing/Optimizing perforating jobs
  - ✓ Numerical modeling of perforating events

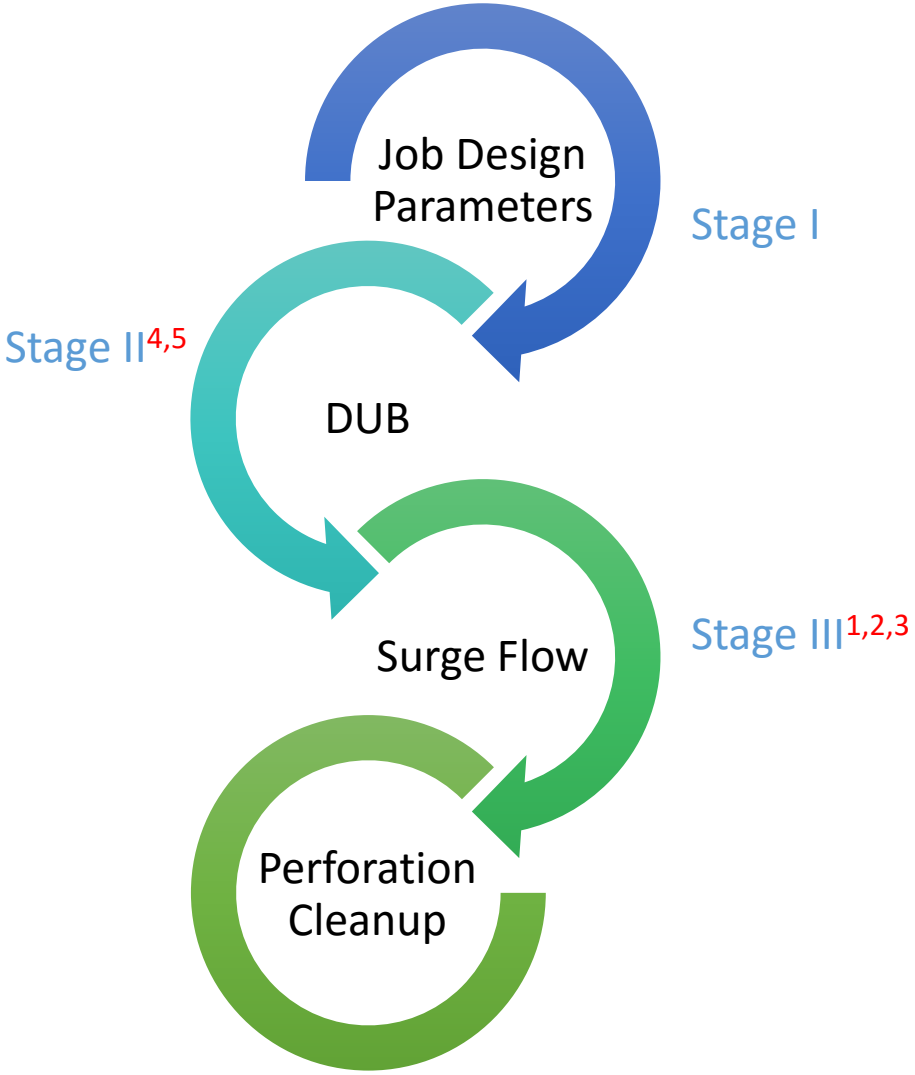
- Challenge – extremely small length scales and arbitrary surface make it impractical for laboratory or traditional modeling methods to quantify the damaged zone.

- Explore the applicability of ***Digital Rock.***





OBJECTIVES



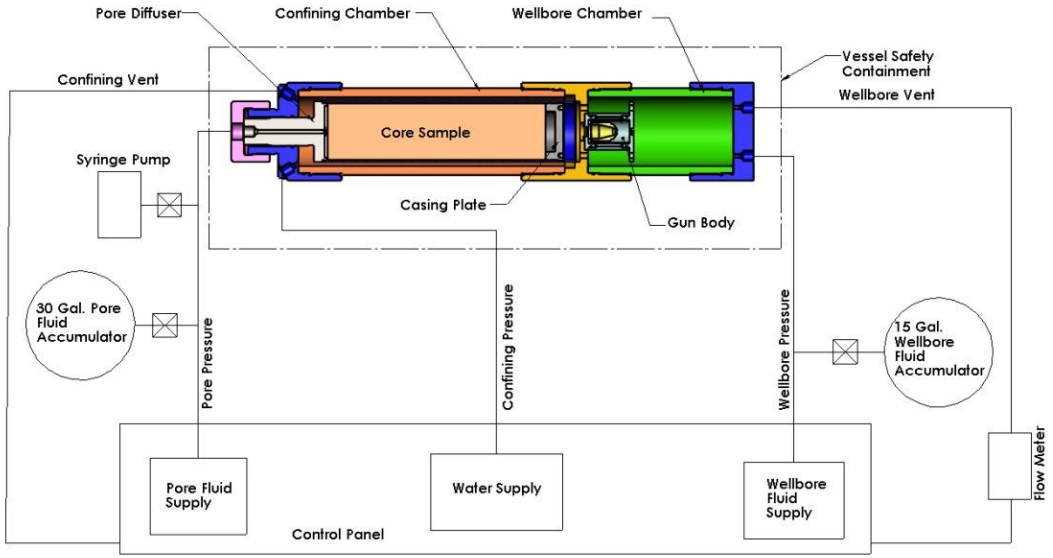
- Application of Digital Rock methodology to characterize and quantify perforation damage in rocks
- Multi-scale simulation approach to accurately predict productivity in perforated rocks
  - ✓ Develop fast physics models for cleanup

[1] King et al., J. Pet. Technol. (1986)
[2] Tariq SPE-20636 (1990)
[3] Haggerty et al., SPE-159413 (2013)
[4] Detwiler et al., SPE-86538 (2004)
[5] Bolchover & Walton, SPE-98220 (2006)

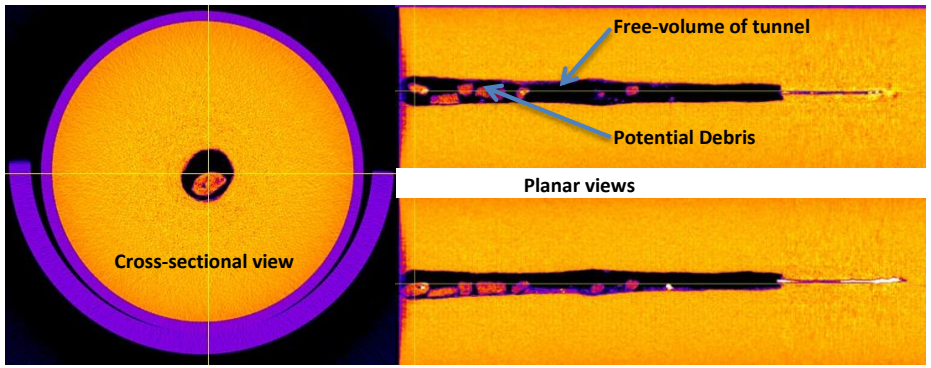
PERFORATION FLOW LABORATORY

The flow laboratory provides the capabilities to:

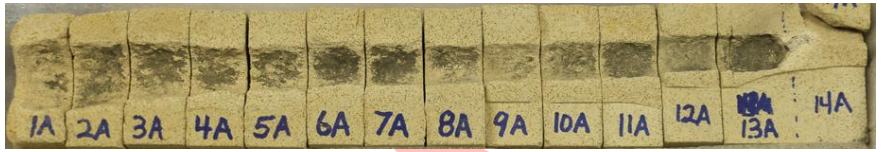
- Study and qualify the performance of different perforating systems in formation rock at reservoir conditions.
- Study the influence of various factors on well productivity.
- Integrate this knowledge to select the optimal perforating system and clean up strategy for improved productivity.



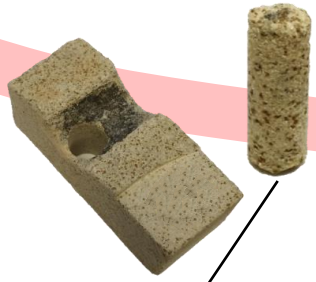
	Section-I	Section-II	Section-II Modified	Section-IV
Target	Concrete	Analog Rock	Analog Rock	Analog Rock
Confining Pressure	Atmospheric	10000	25000	15000
Fluid	Not Applicable	Saturation fluid (OMS)	OMS/Brine	OMS/Brine
Wellbore Pressure	Not Applicable	Not Applicable	25000	10000
Pore Pressure	Not Applicable	Not Applicable	25000	10000
Temperature	Not Applicable	500F	300F	300F
Pre-shot Flow	Not Applicable	Not Applicable	Not Applicable	Applicable
Post-shot Flow	Not Applicable	Not Applicable	Not Applicable	Applicable

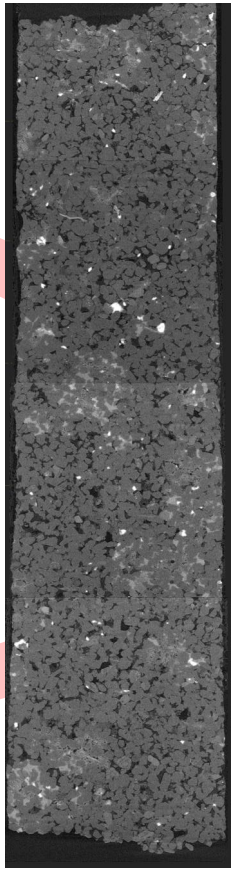


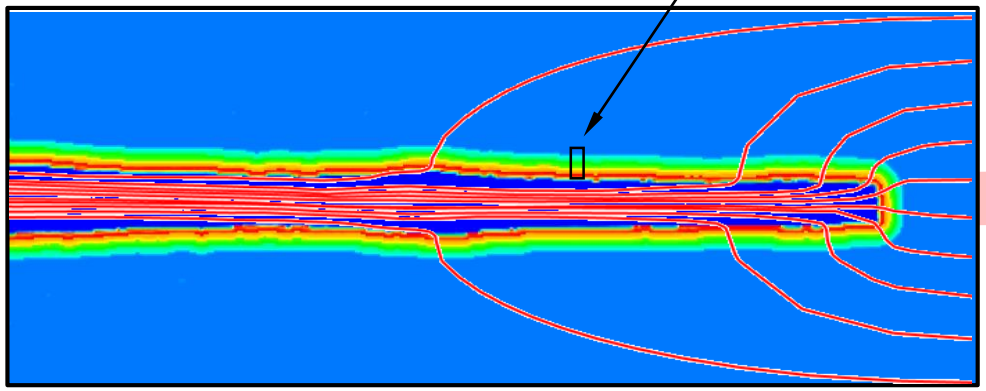
WORKFLOW OVERVIEW

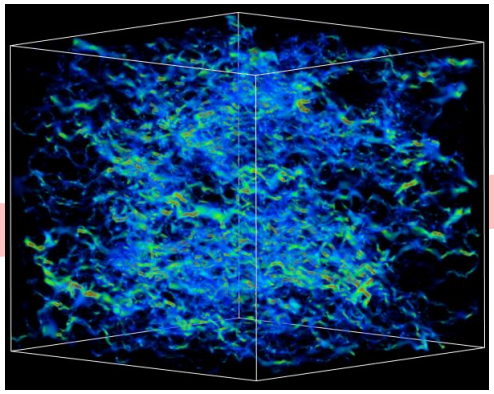


- Section-IV test
- Extract plugs
- CT evaluation
- Pore Space Analysis
- Lattice Boltzmann Simulation
- Permeability Evaluation
- Macro Production Model





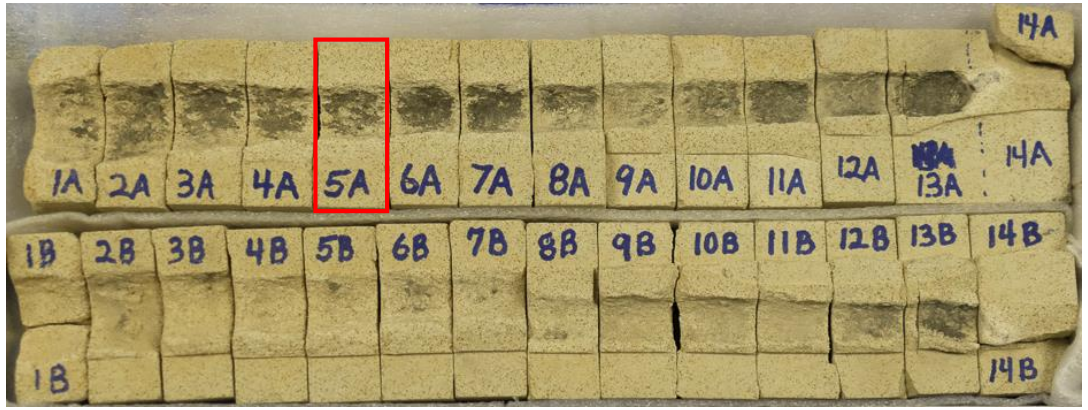


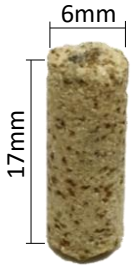


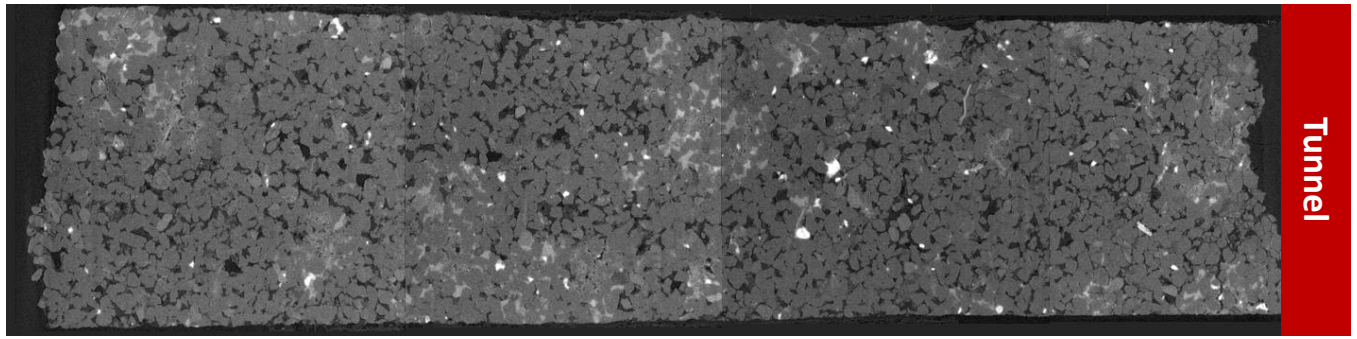
DAMAGE CHARACTERIZATION

IMAGE ACQUISITION

- 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 (2µm resolution)
- Resulting scans provide detailed pore space geometry for flow simulation analyses



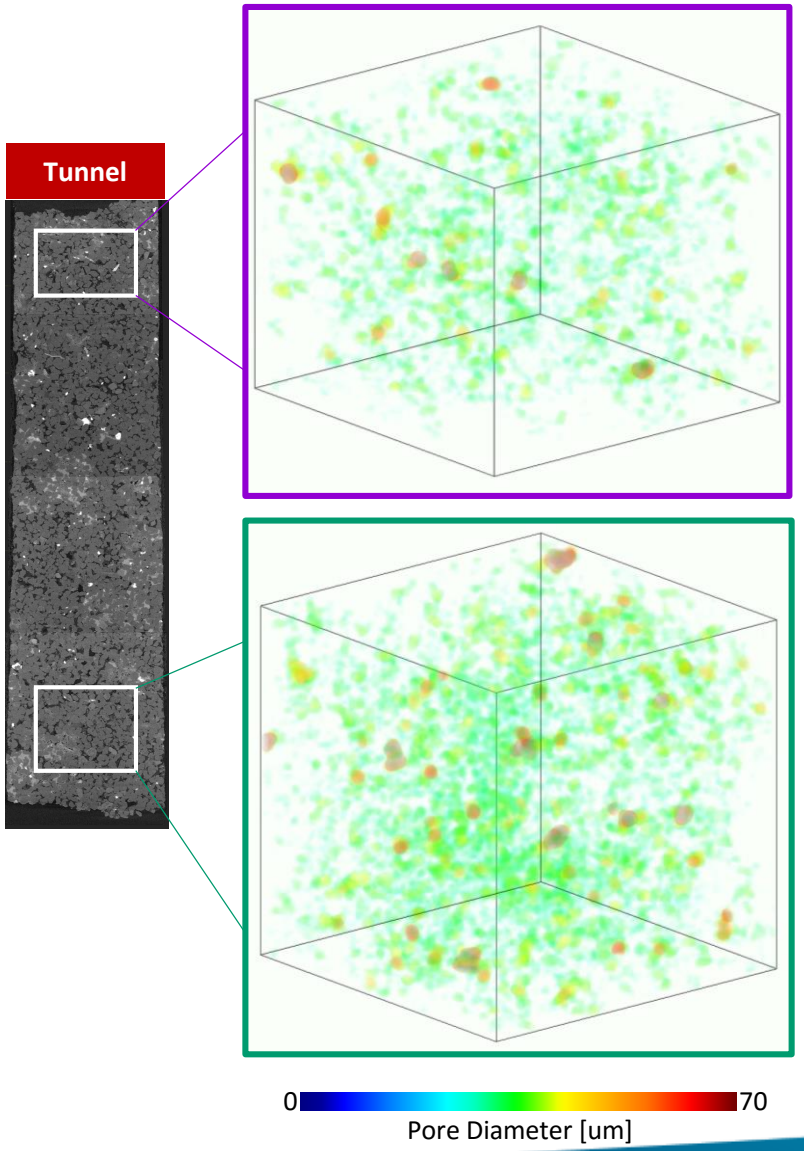


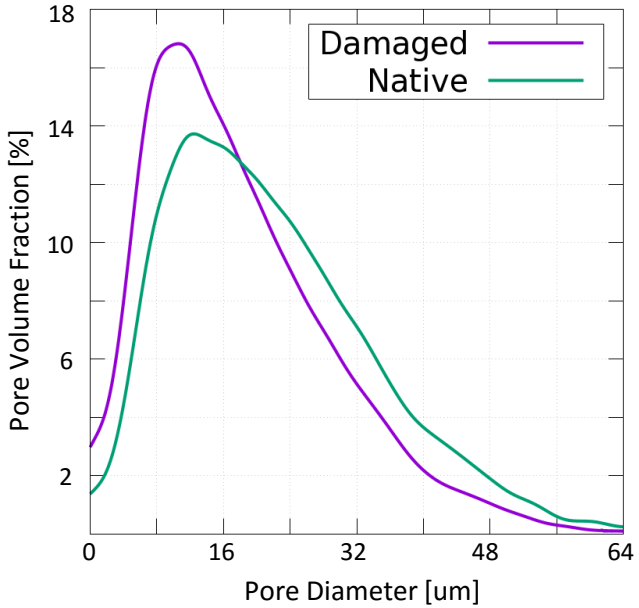


DAMAGE CHARACTERIZATION

PORE SPACE ANALYSIS

- Pore size is calculated with a maximum balls algorithm
- Pore size distributions of the sub-images are compared

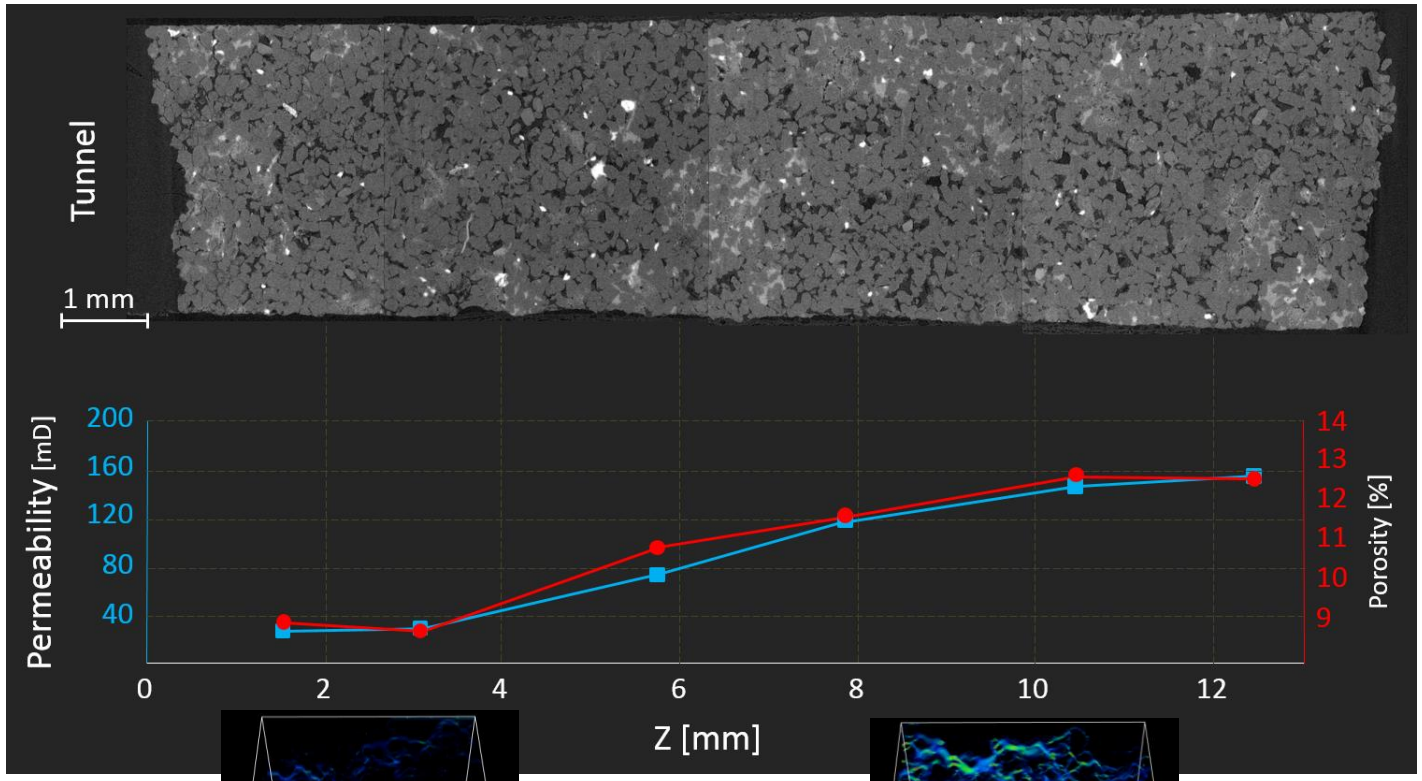


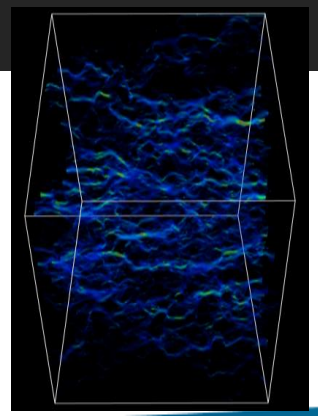


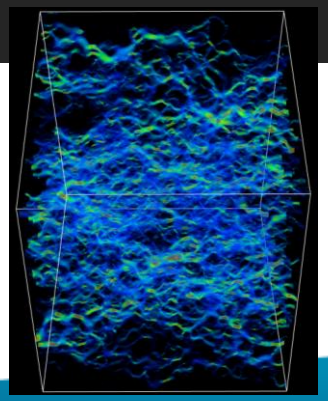
DAMAGE CHARACTERIZATION

PERMEABILITY EVALUATION

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



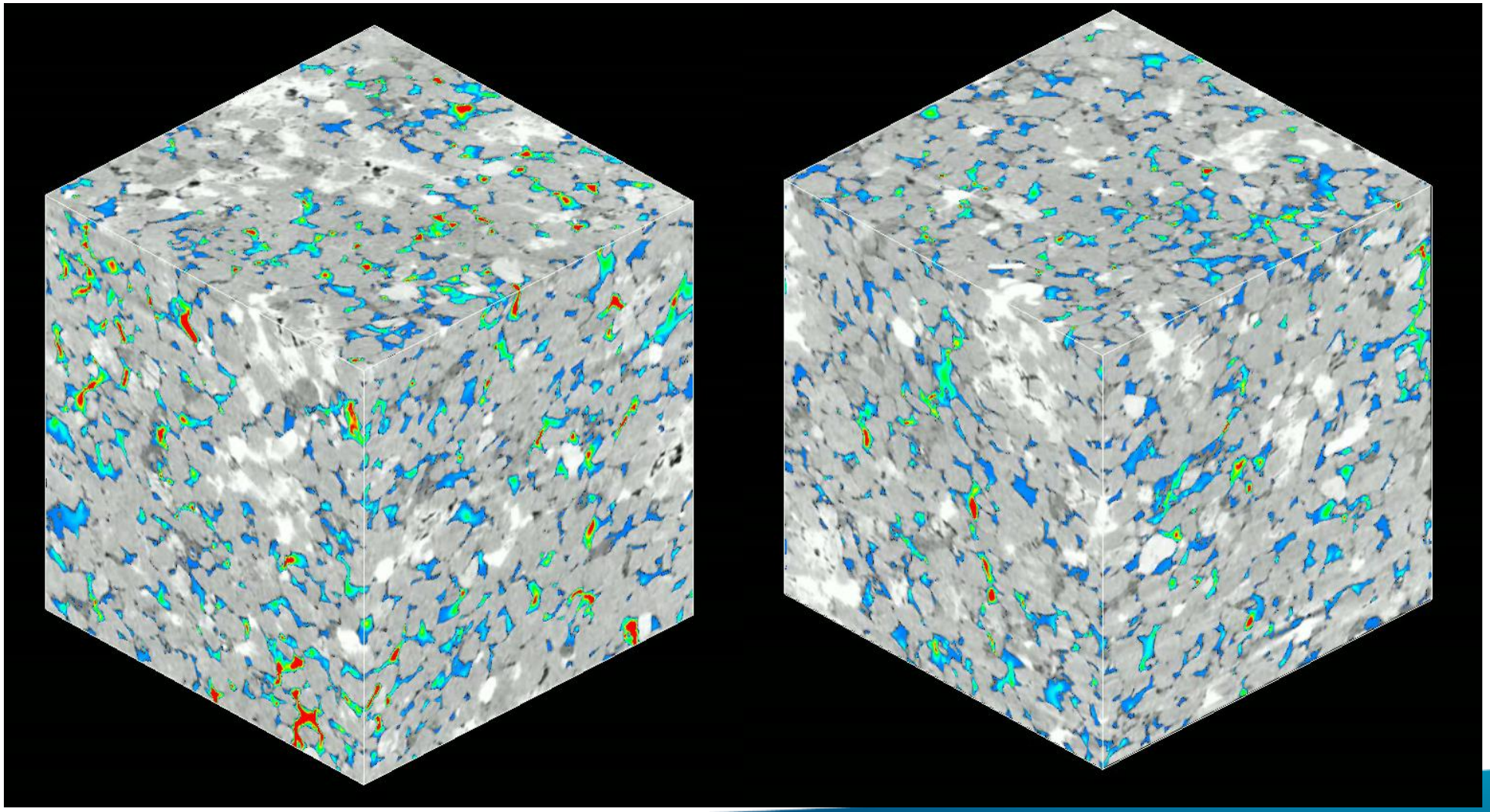




DAMAGE CHARACTERIZATION

WHOLE FIELD VISUALIZATION

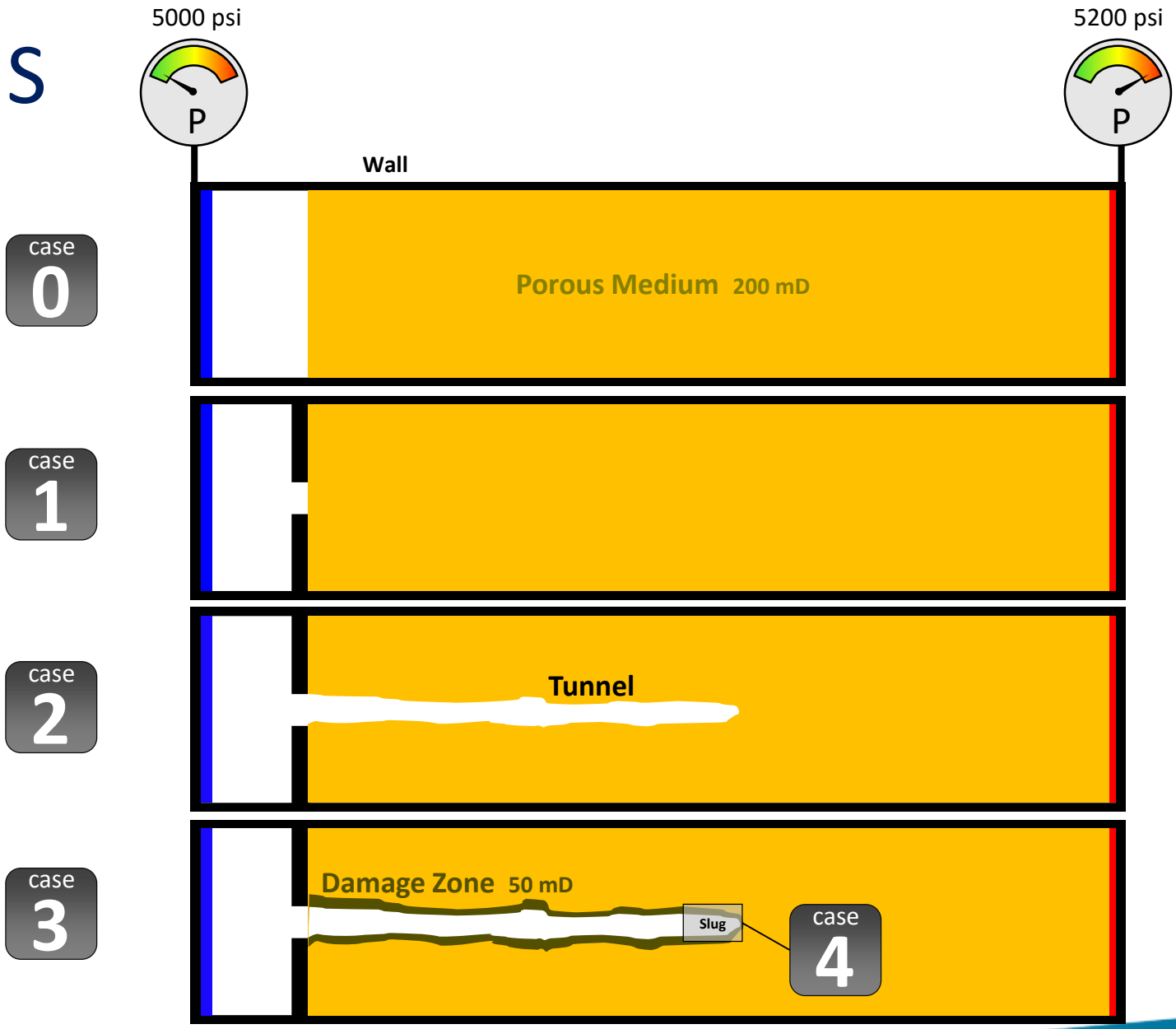
Native: Porosity=12.5%, K0 = 139 mD **Damaged: Porosity=11.0%, K0 = 61 mD**



PRODUCTIVITY ANALYSIS

PERFORATION TUNNEL MODELING

- Simulations performed using Lattice-Boltzmann method with porous media model
- Native rock permeability 200 mD
- Damage zone permeability 50 mD



PRODUCTIVITY ANALYSIS

PRODUCTIVITY RATIO RESULTS

- Various scenarios and effects easily studied

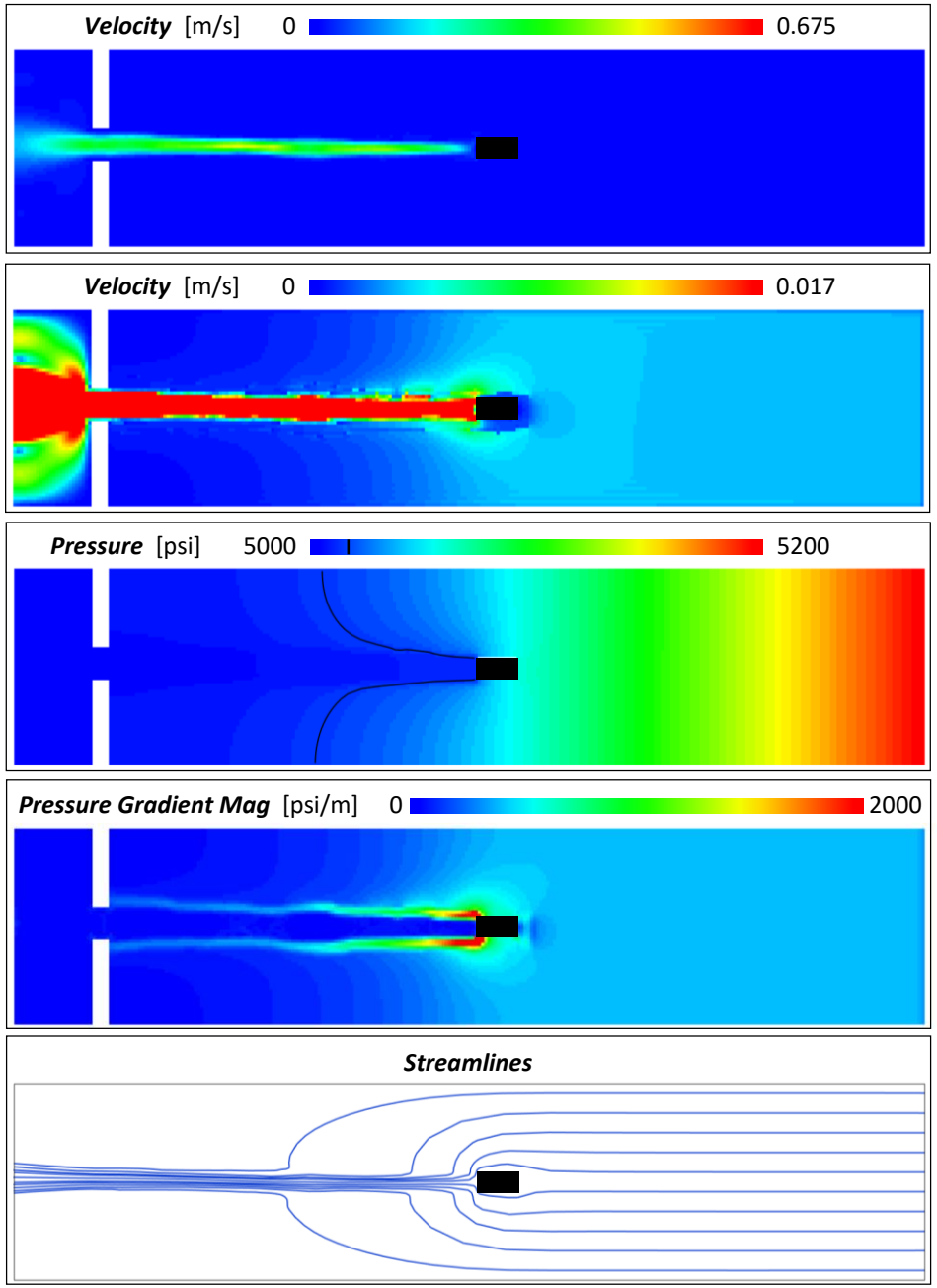
	Case Layout	Productivity	Productivity Ratio
case 0		3.55 l/min	1
case 1		2.71 l/min	0.76
case 2		5.95 l/min	1.68
case 3		5.67 l/min	1.6
case 4		5.29 l/min	1.49

PRODUCTIVITY ANALYSIS

FLOW VISUALIZATION

Case 4: Damage & Slug

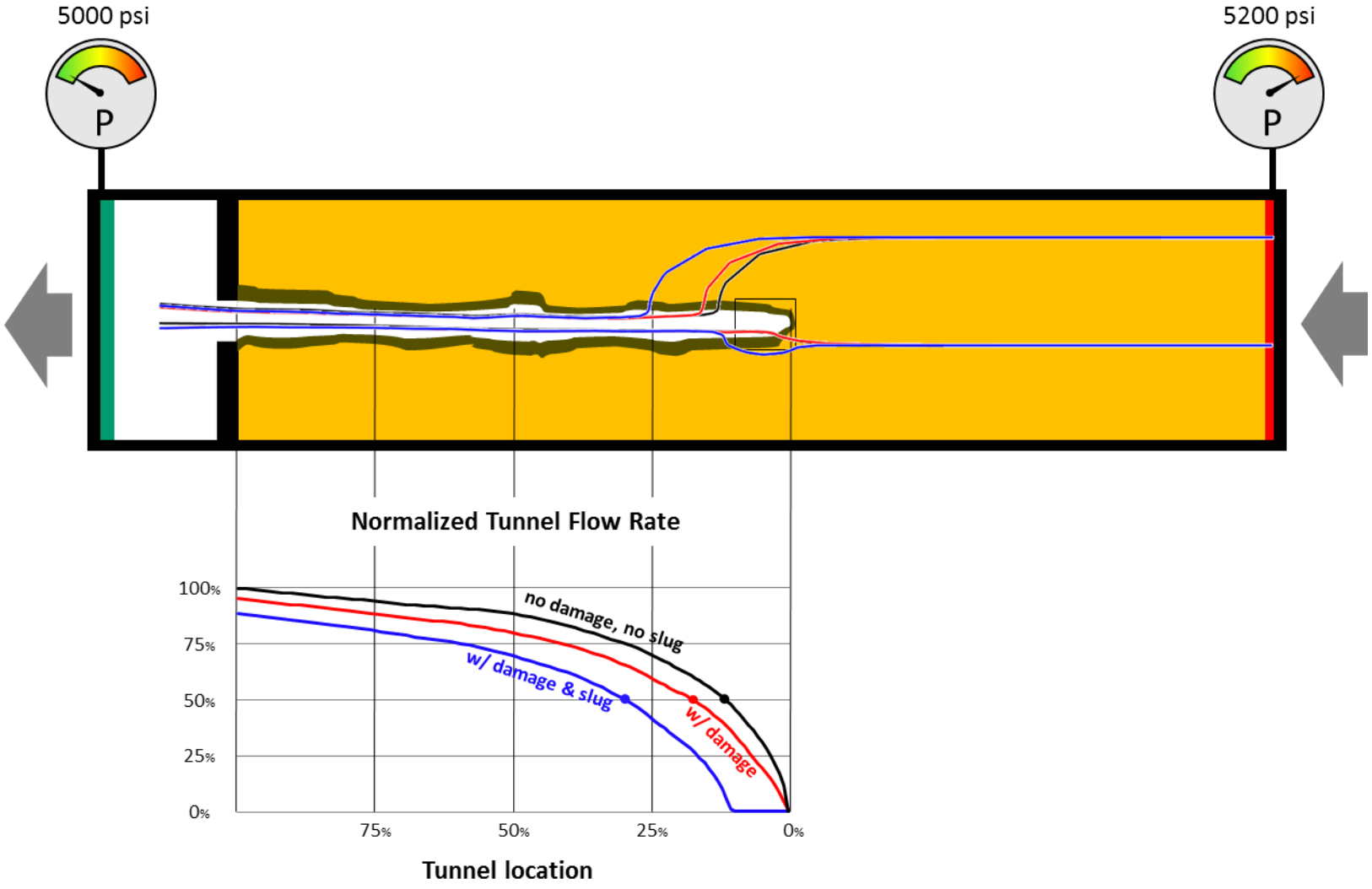
- Nearly all of the pressure drop occurs from the inlet to the toe
- Flow concentrates at the toe of the tunnel, causing highest pressure gradient.



PRODUCTIVITY ANALYSIS

FLOW VARIATIONS

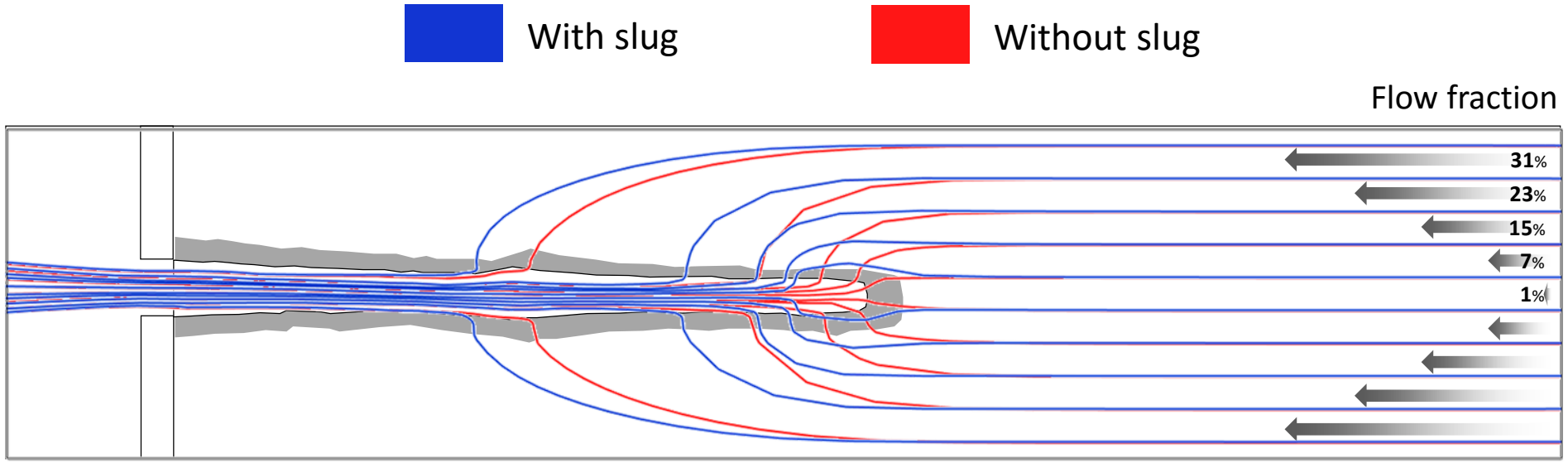
- Presence of damage zone moves the tunnel flow entry downstream
- Presence of slug increases the effect



PRODUCTIVITY ANALYSIS

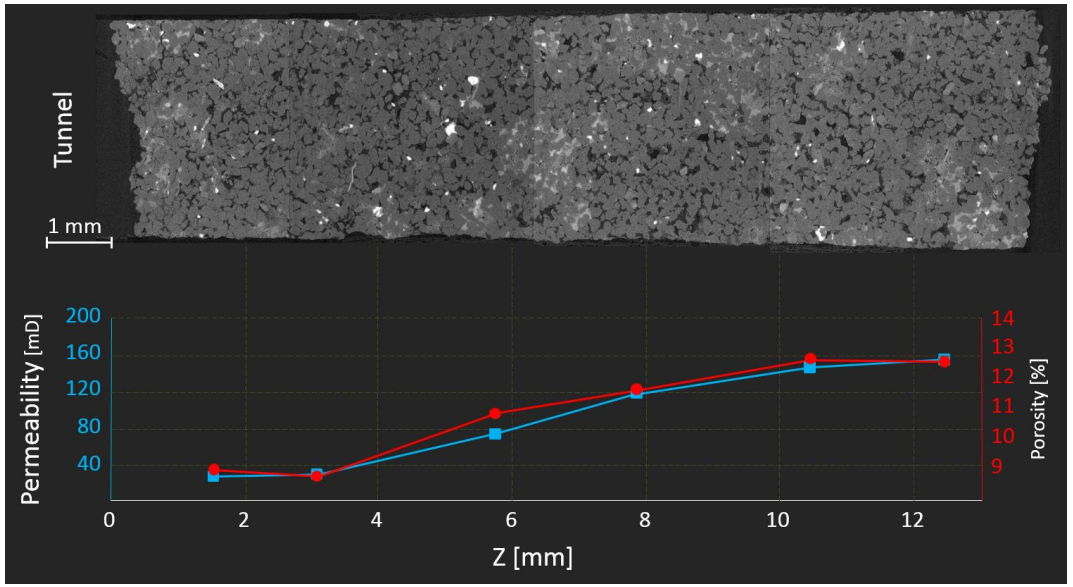
SLUG EFFECT

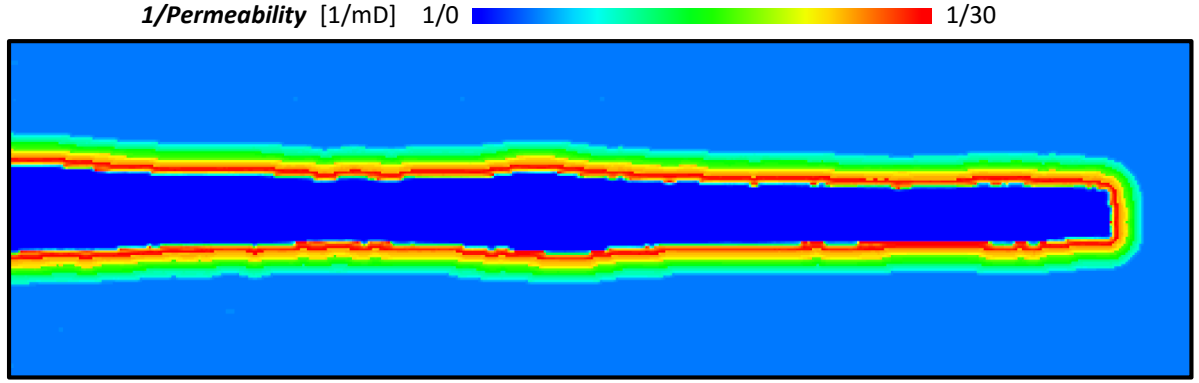
- Introducing a slug to the toe of the tunnel shifts the flow entry downstream.



CONCLUSIONS

- Multi-scale approach to modeling perforation tunnel productivity is demonstrated
- Pore scale simulations are important to quantify the damage zone permeability
- Resulting permeability characterization allows detailed perforation productivity analysis
- Future Work
  - Couple results to fast-physics models for DUB (See MENAPS 16-25)
  - Realistic reservoir domain
  - Upscale from lab-to-field scale flow modeling





QUESTIONS?
THANK YOU!