Perforation Damage, Cleanup, and Inflow Performance: Advances in Diagnostics and Characterization

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Outline

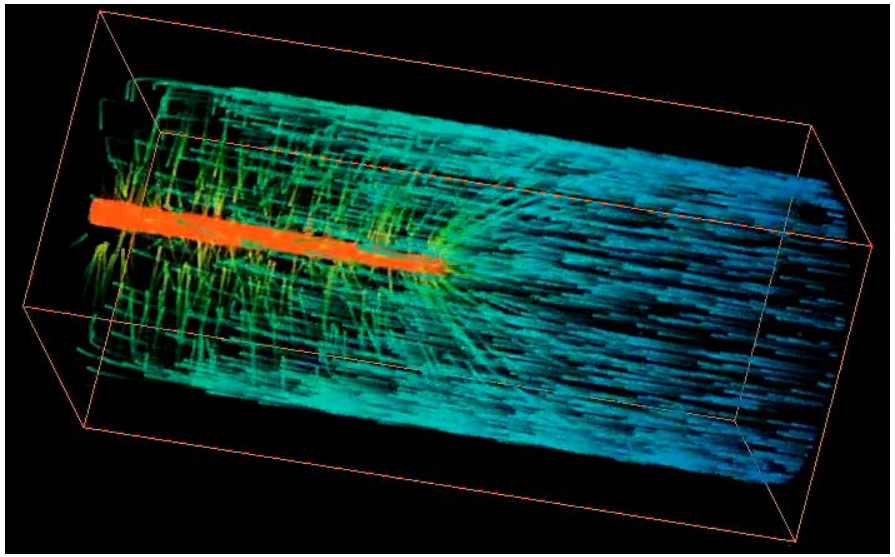
- Research program overview
- Status and interim results
- Conclusions & future work

Research Program Overview

- 2 main threads
  - Perforation damage characterization
  - Cleanup & flow performance
- Approach
  - Integrate Ingrain's diagnostic and analysis capabilities with Advanced Perforating Flow Laboratory activities
- Workflow
  - Perforate core at prescribed conditions
  - CT scan onsite – in flow laboratory
  - Further CT scanning, micro-CT, analysis – at main campus

End game(s)

- Perf damage – nature and mechanisms
- Mechanistic cleanup models
- Different rocks ("perf damage" in shale?)
- Simulate perforation inflow (ultimately 3D, accounting for perm heterogeniety & anisotropy)
- Better interpret Section IV results; apply to downhole



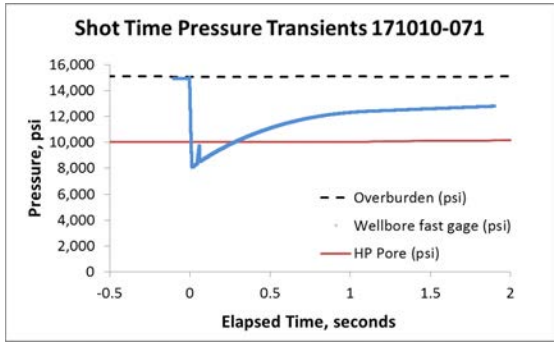
Status

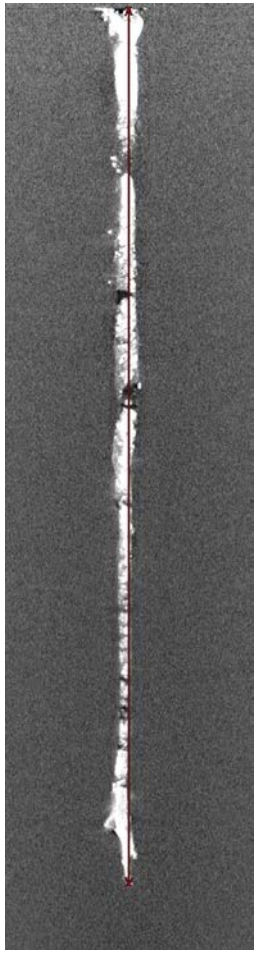
- Initial focus – perf damage (no flow)
- Several cores have been perforated for this effort
  - Sandstones, carbonates; range of strength, porosity, permeability
  - Varying levels of cleanup (via DUB)
- Preliminary analysis conducted on 2 cores
  1. Berea sandstone – no cleanup (crushed zone preserved, tunnel filled with liner debris)
  2. Crab Orchard sandstone – "full" cleanup (tunnel substantially empty, with some small crushed zone remaining)

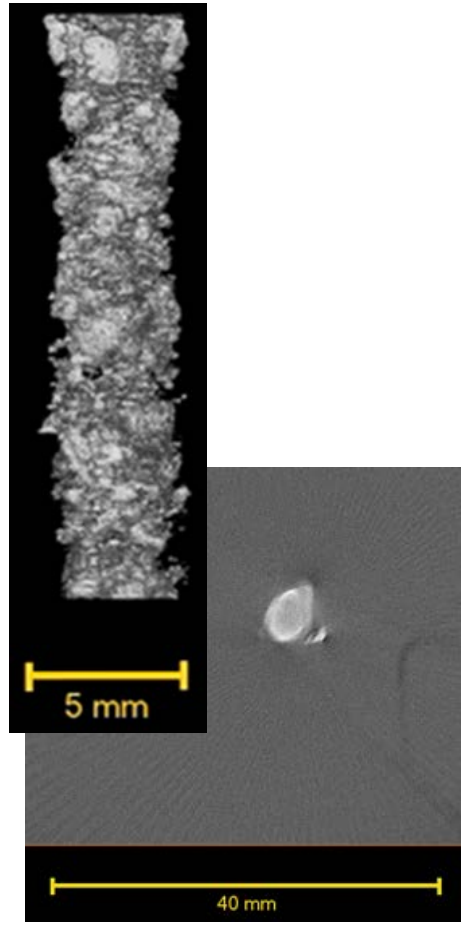
- Interim results – following slides

Interim Results – Berea

Core = Berea Sandstone		
Dim (in)	Length	24
	Diameter	7
Properties	UCS (psi)	6,294
	Porosity	21.0%
	Saturation	OMS
Test pressures (psi)	Overburden	15,100
	Pore	10,000
	Wellbore	15,000

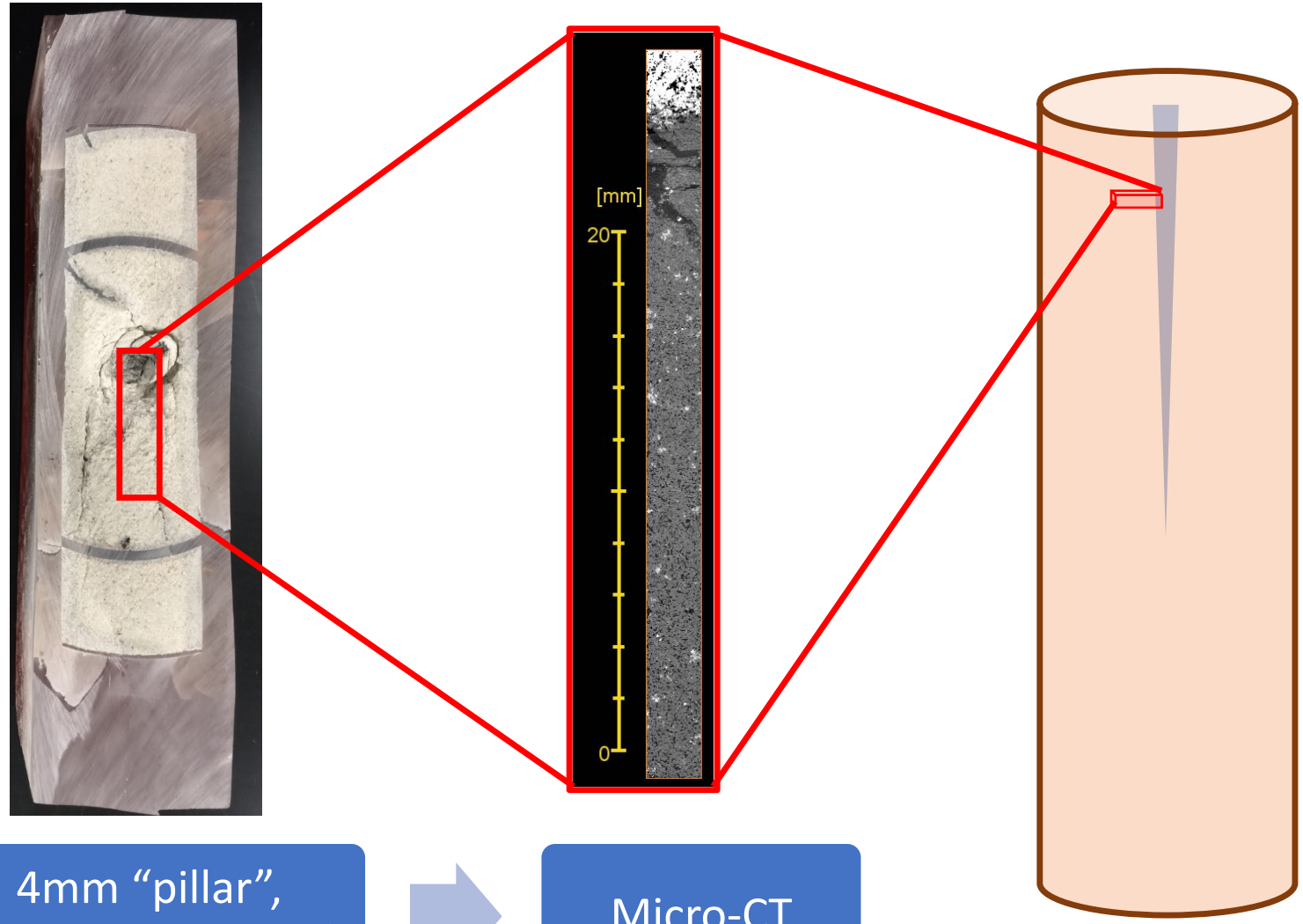






Perforate → Full-core scan of perforation → Overcore to 4” → Re-scan; higher res → *Next slide*

Interim Results – Berea

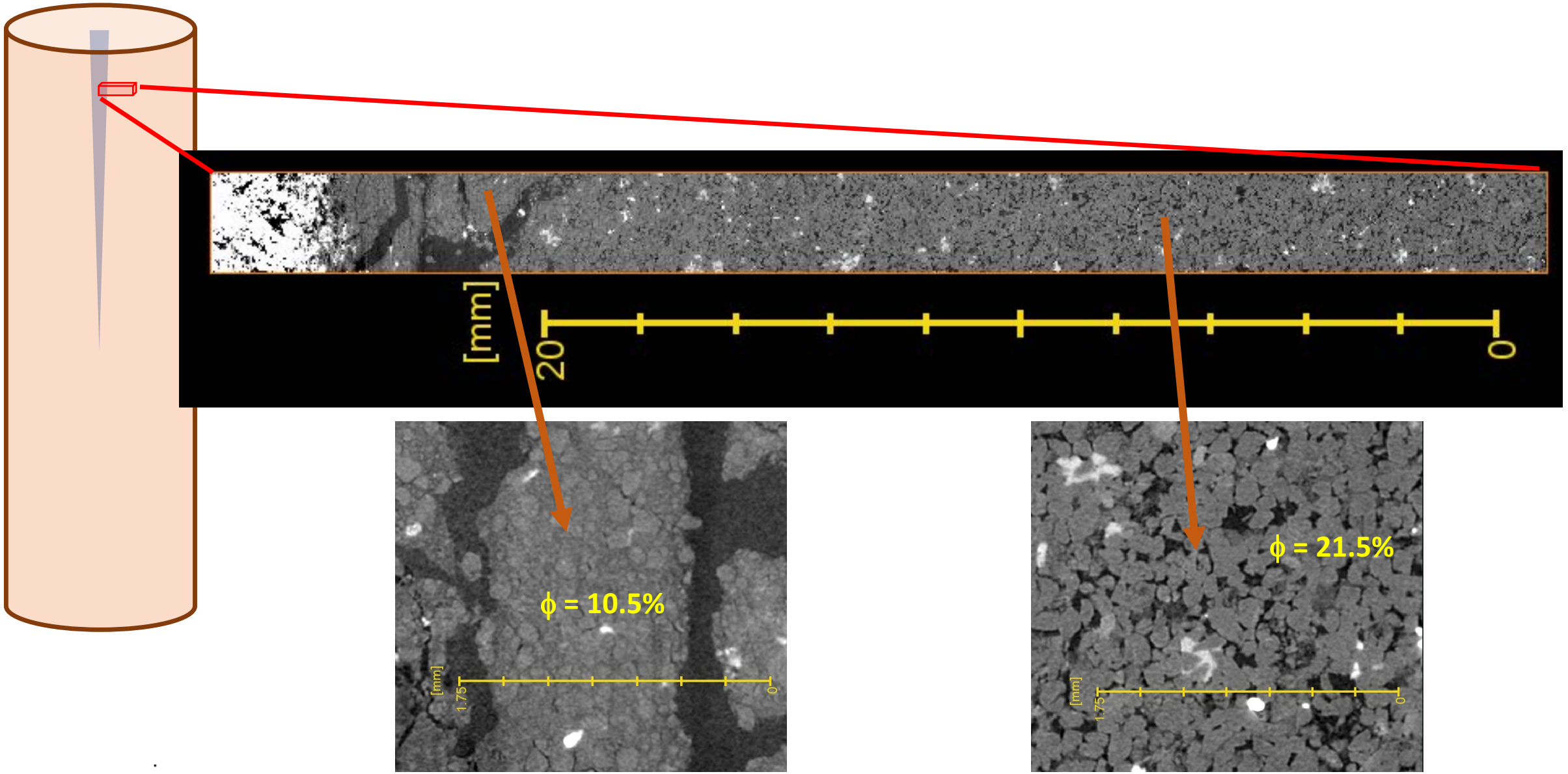


Overcore to 2-1/4”

4mm “pillar”, orthogonal to perf

Micro-CT

Interim Results – Berea



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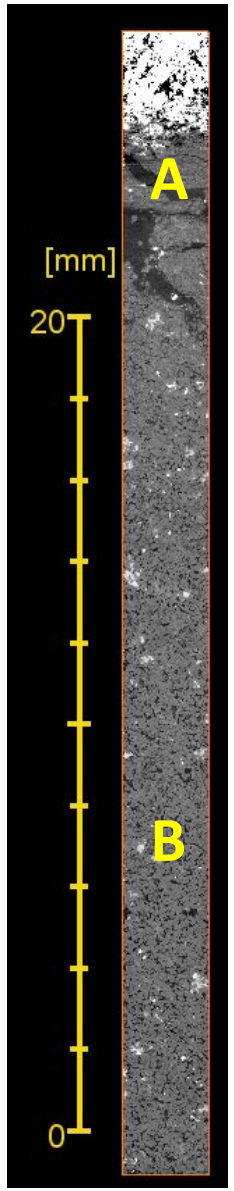
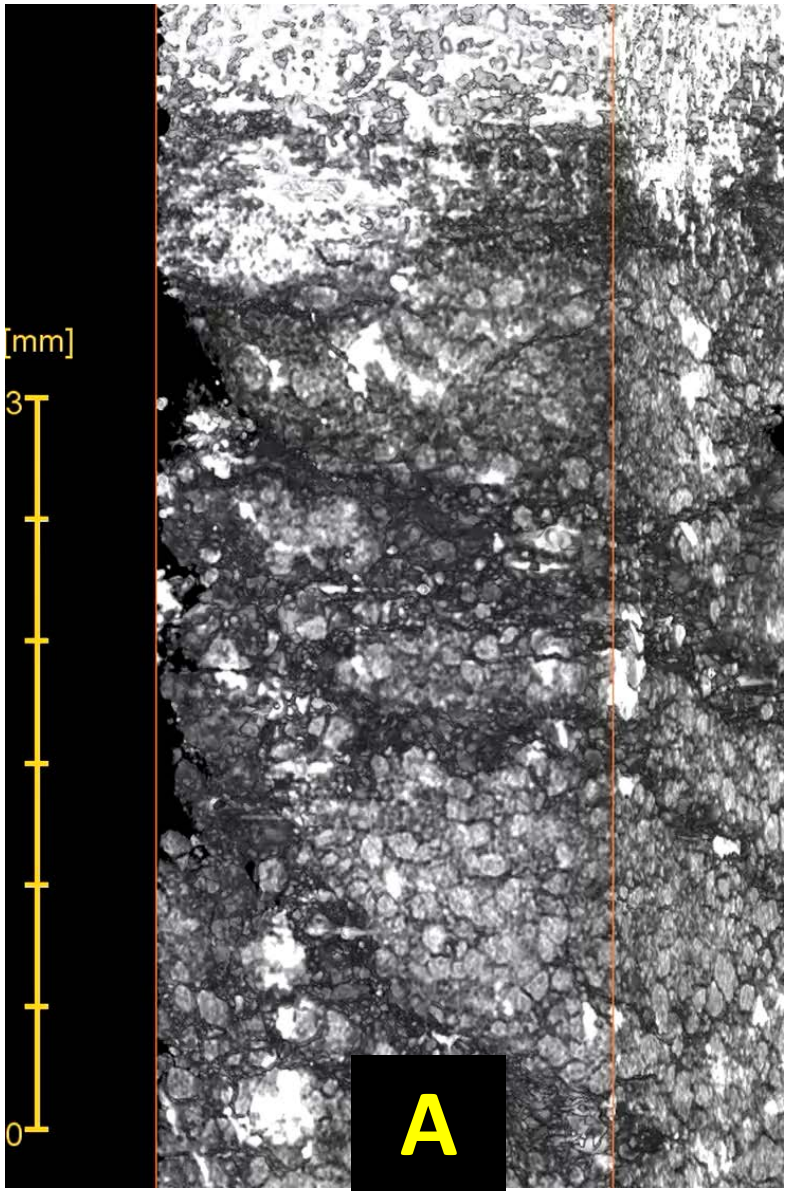
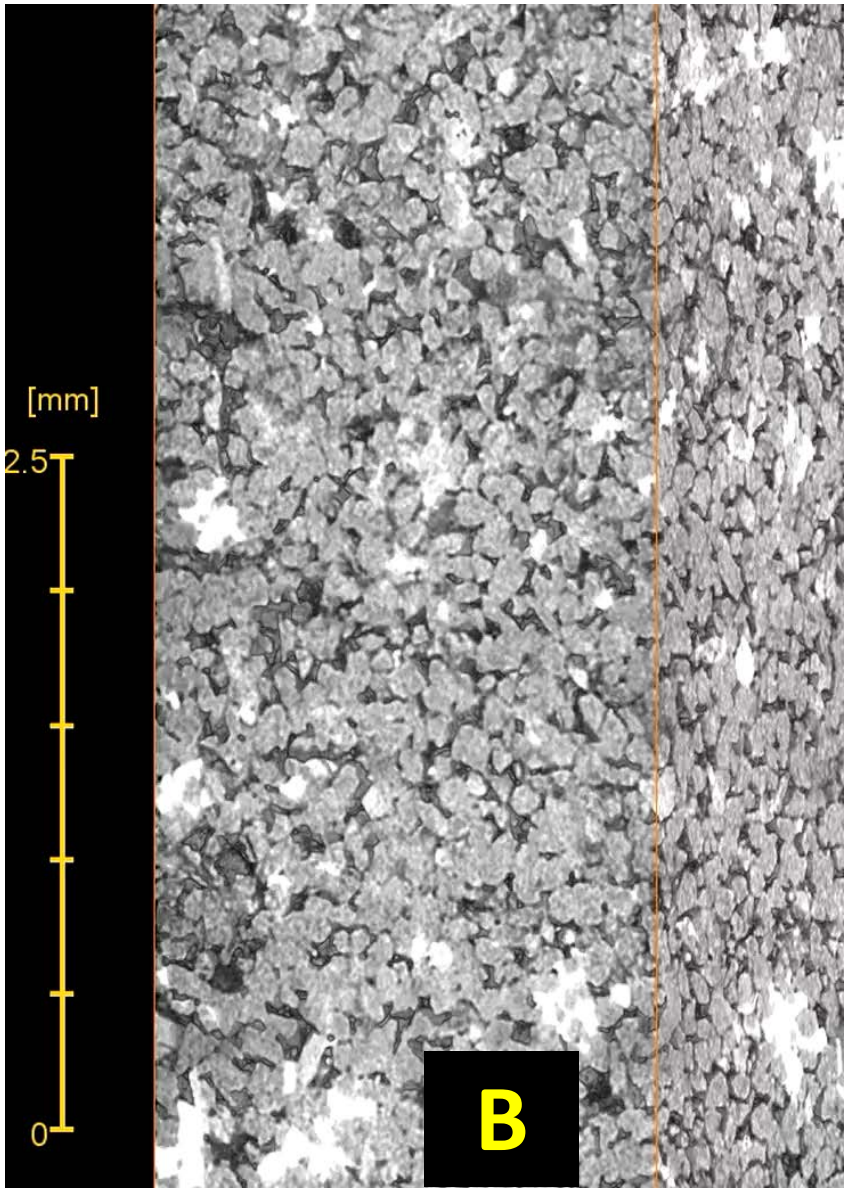
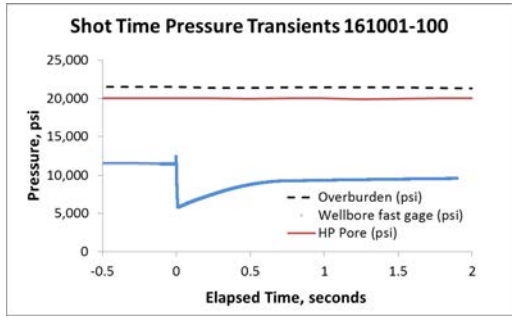


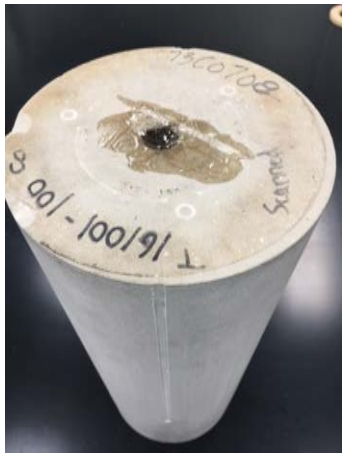


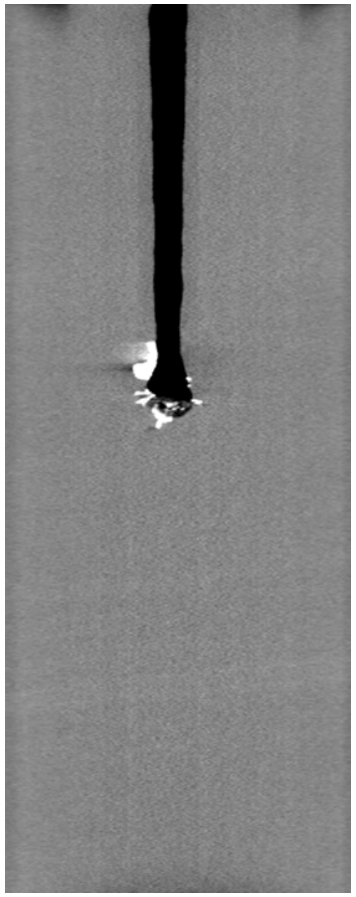


Interim Results – Crab Orchard

Core = Crab Orchard Sandstone		
Dim (in)	Length	18
	Diameter	7
Properties	UCS (psi)	22,474
	Porosity	10.7%
	Saturation	OMS
Test pressures (psi)	Overburden	21,500
	Pore	20,000
	Wellbore	11,500



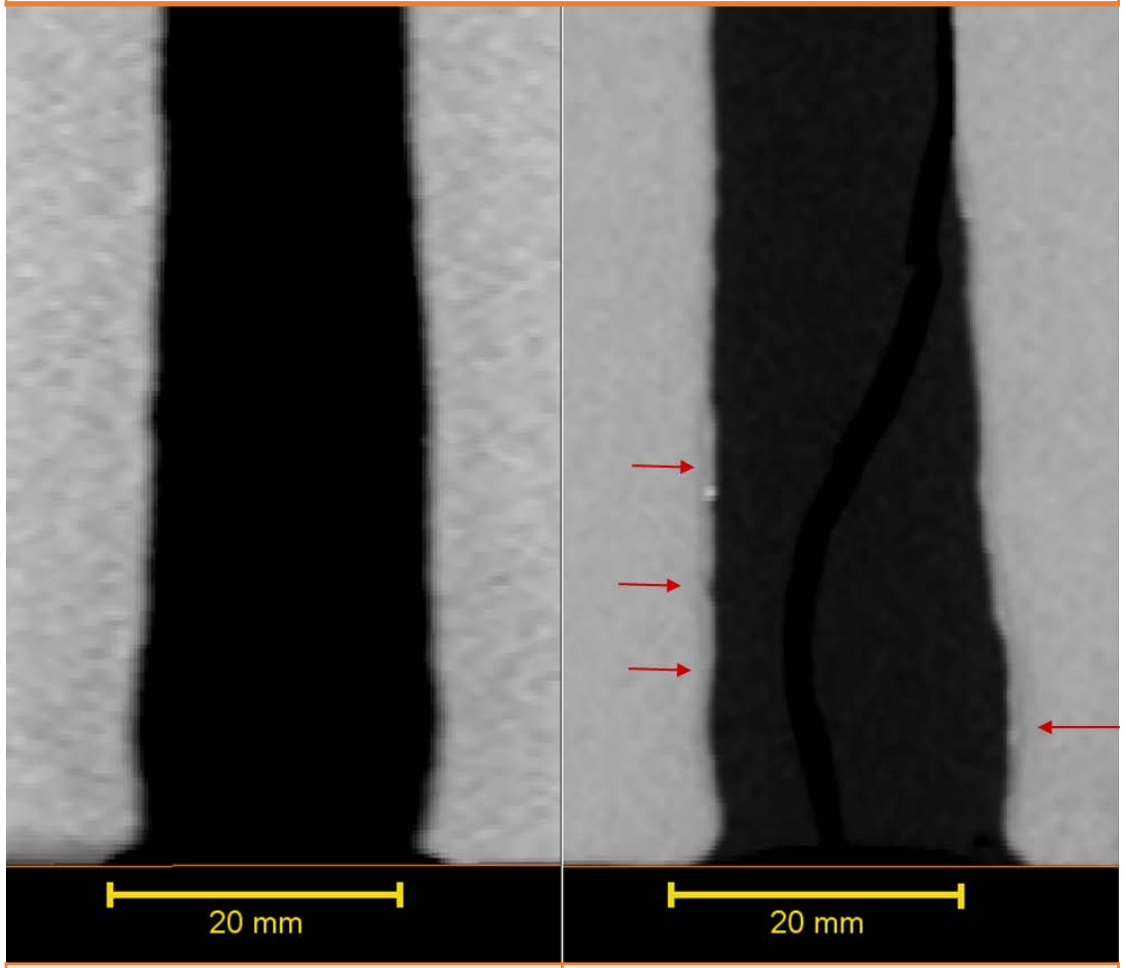




Perforate → Full-core scan of perforation → Overcore to 2-1/4” → Re-scan → *Next slide*

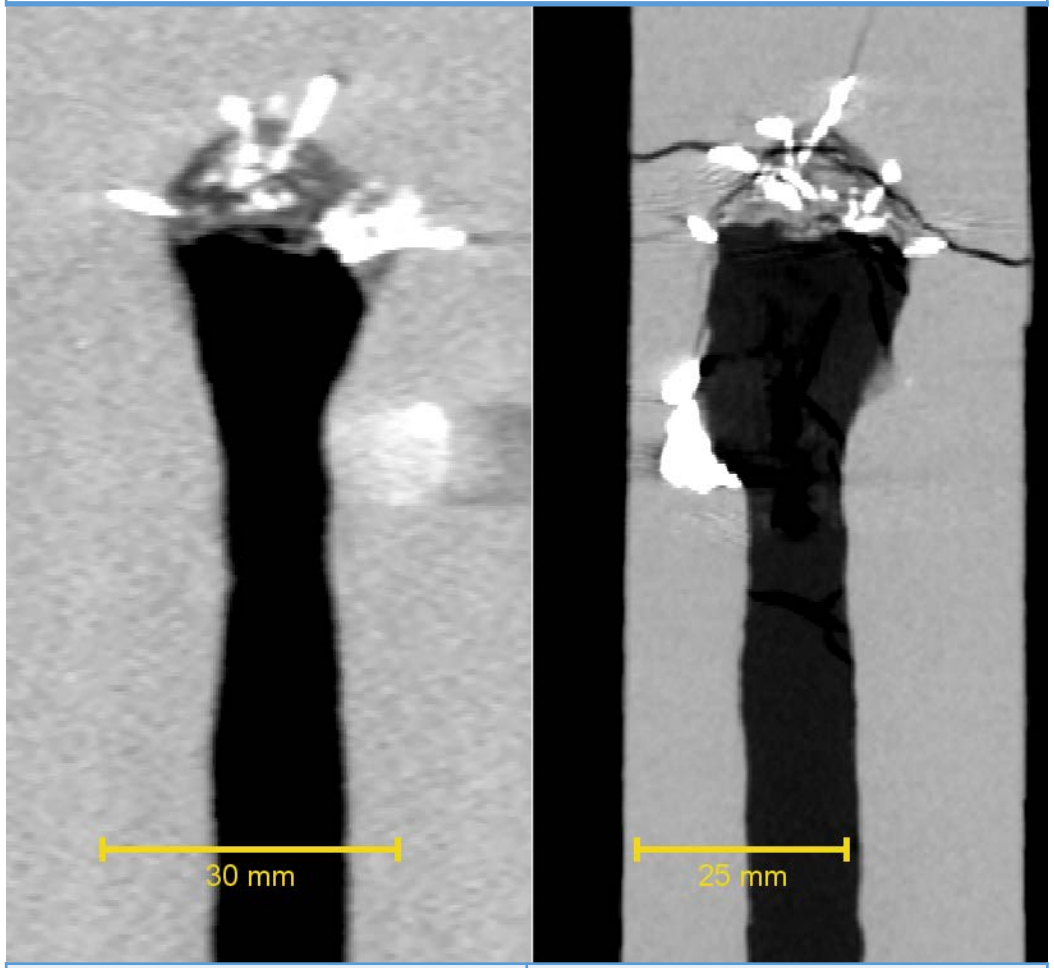
Interim Results – Crab Orchard

Tunnel Entrance



7” core | **2-1/4” core**

Tunnel Tip



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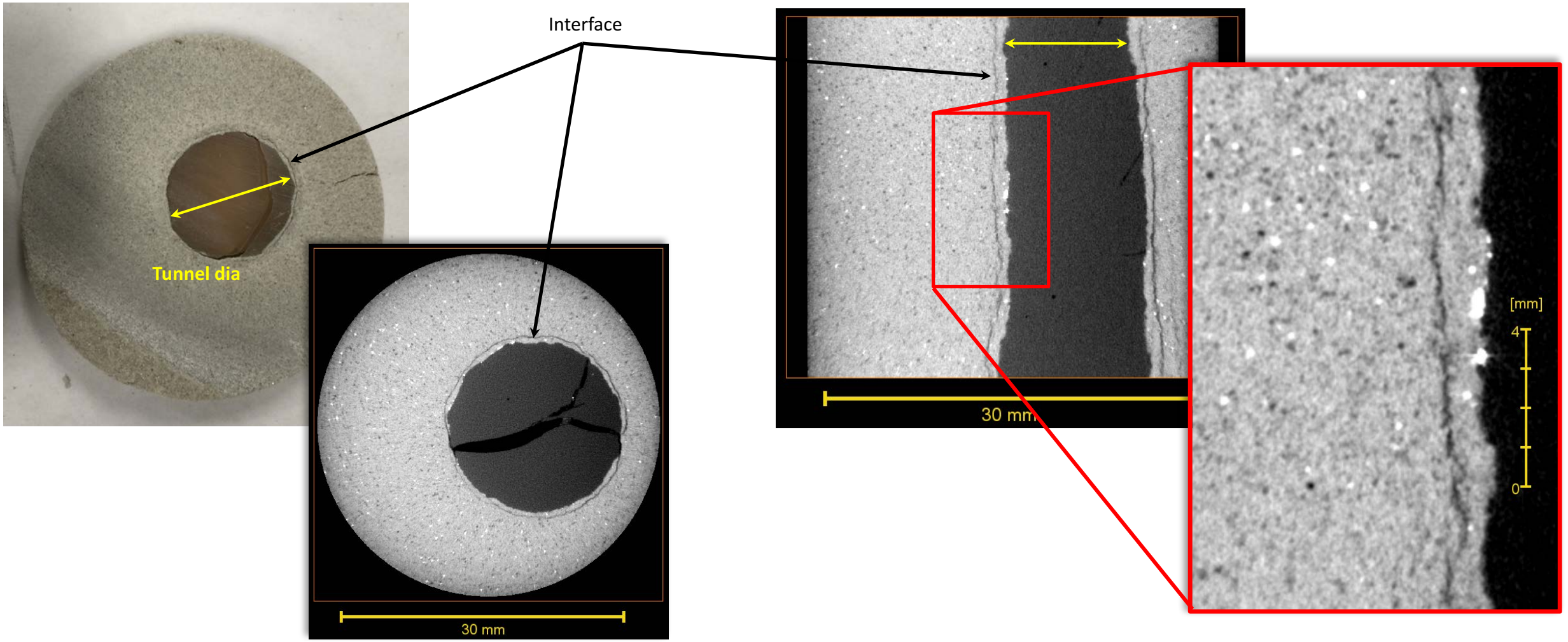
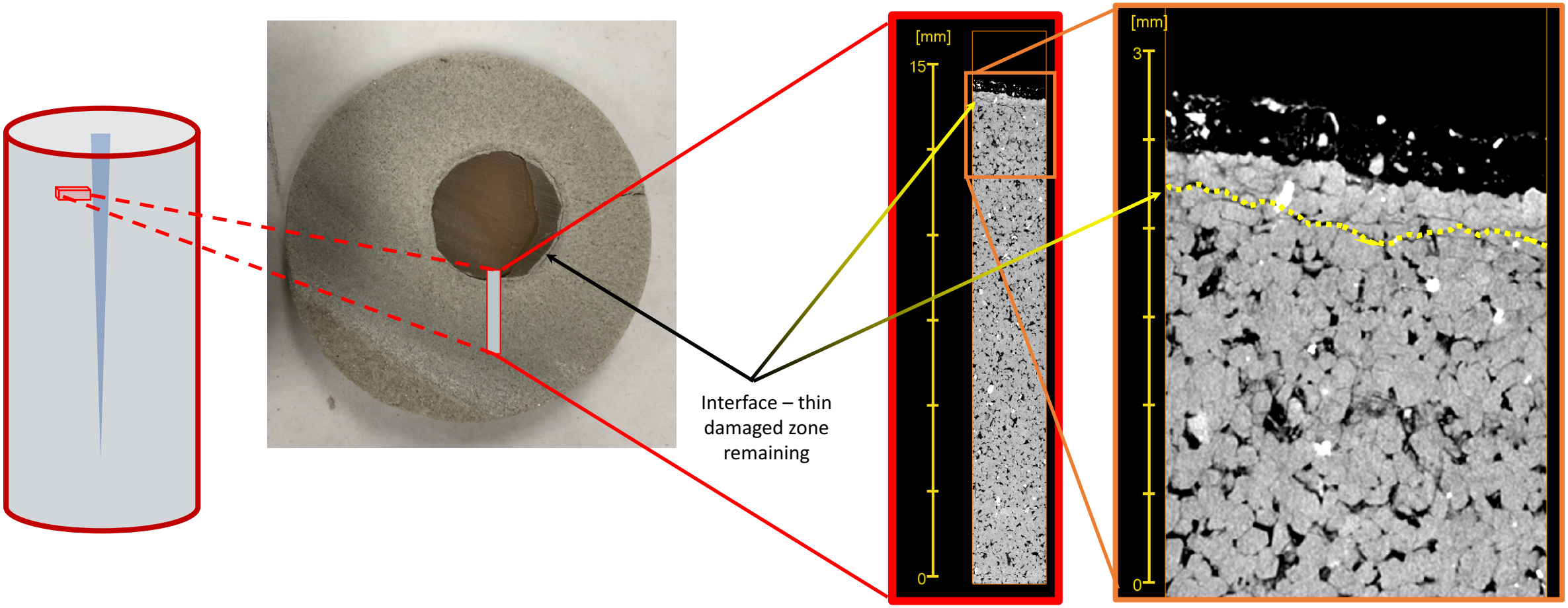


Hi-res scan of 2-1/4” dia disk, focusing on region near perforation tunnel

Interim Results – Crab Orchard



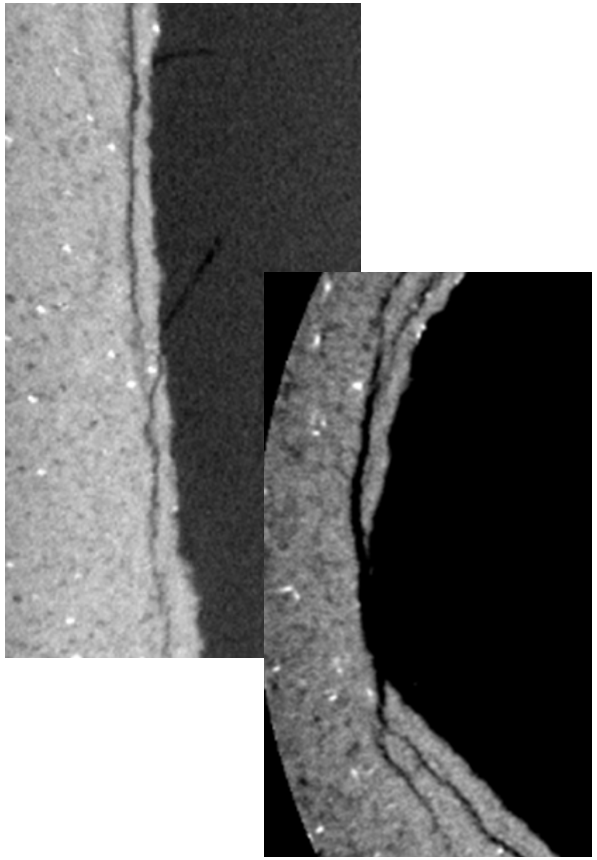
4mm “pillar”, orthogonal to perf

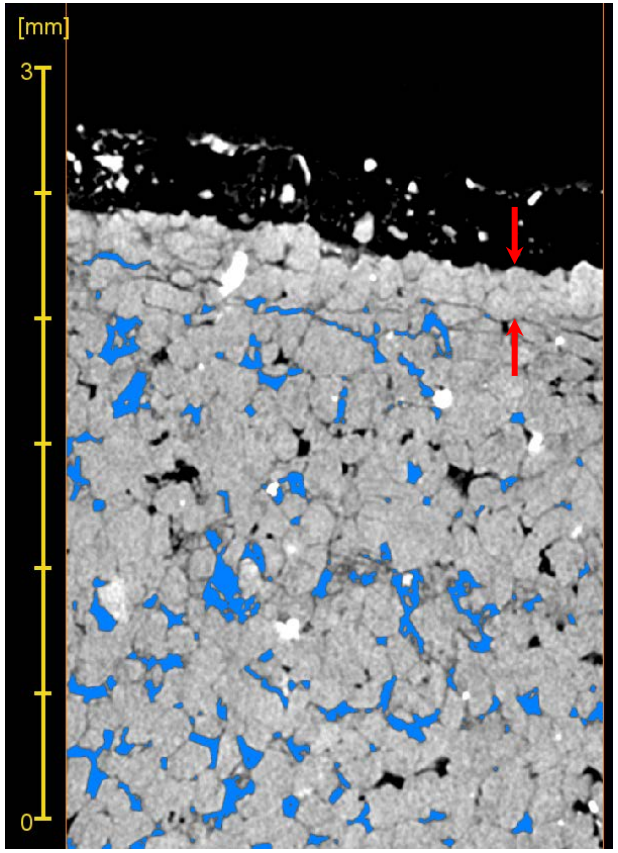
Micro-CT

Interim Results – Crab Orchard

First look at porosity

- Crushed zone
  - Mostly removed, though thin layer remains (t_c < 1mm)
  - Porosity appears reduced (as with Berea core)
  - Connected porosity significantly reduced (implies k_c/k << 1)





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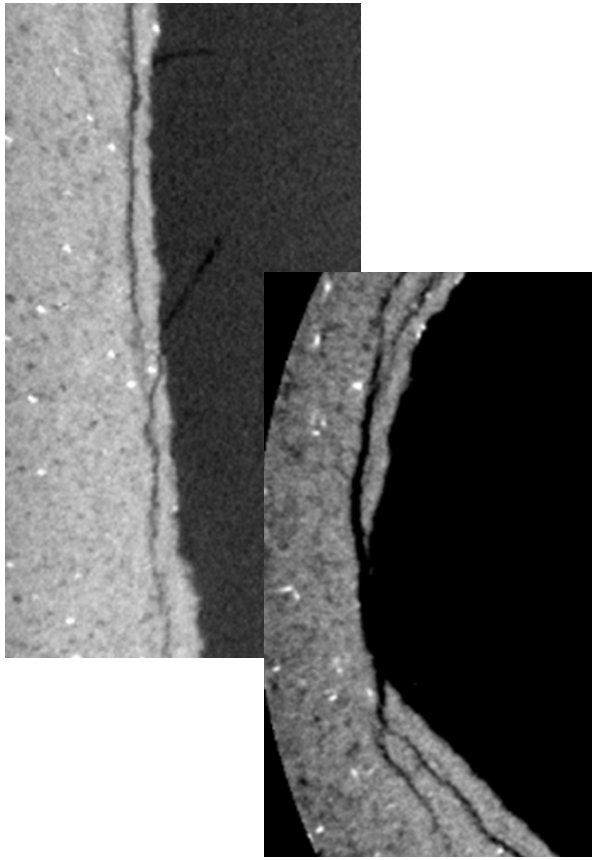
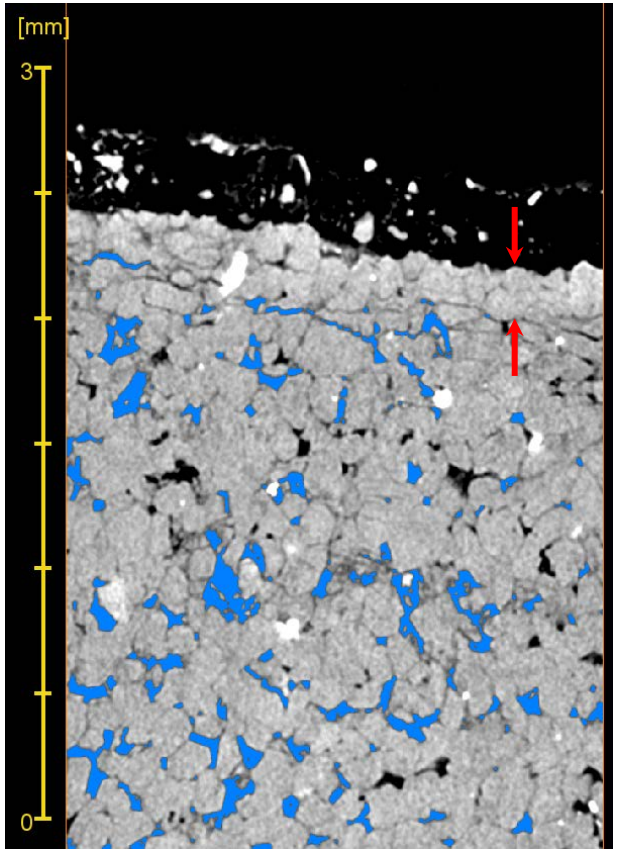
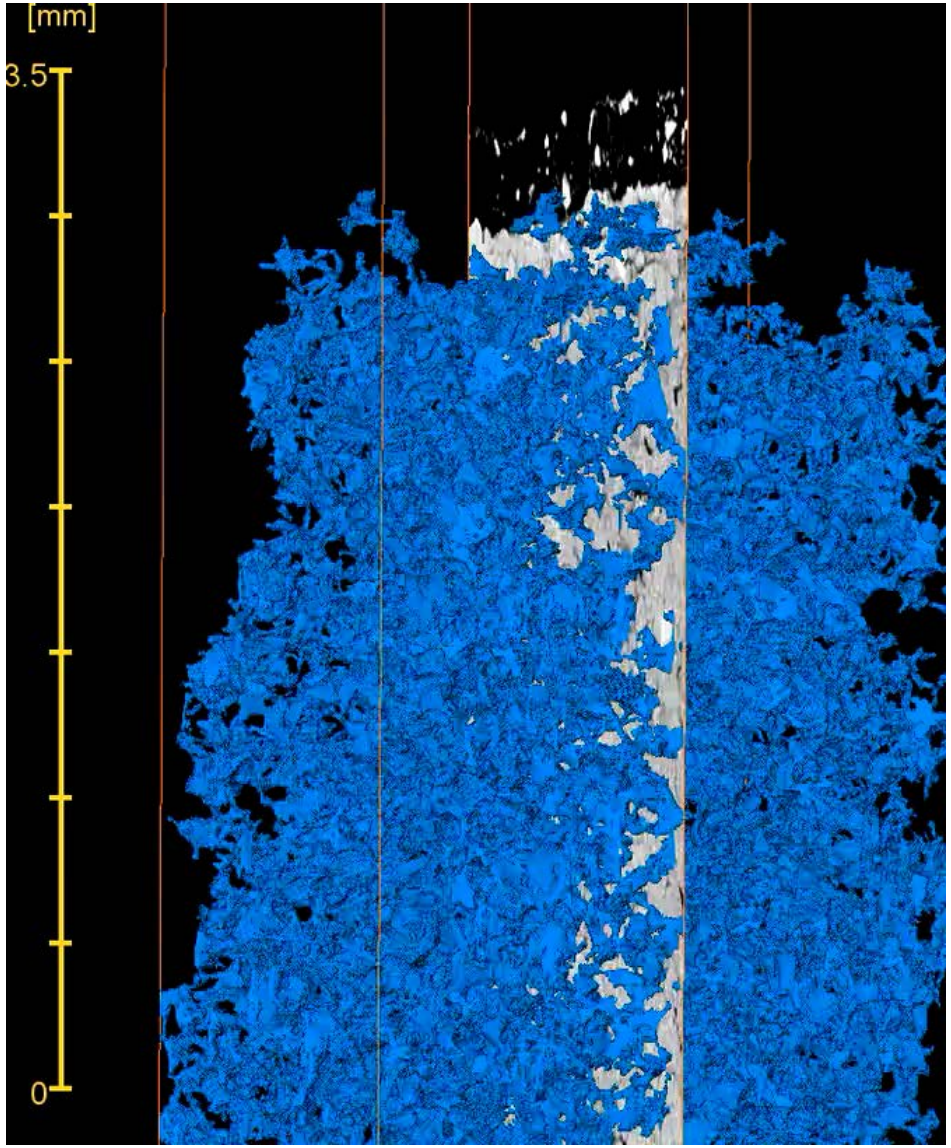
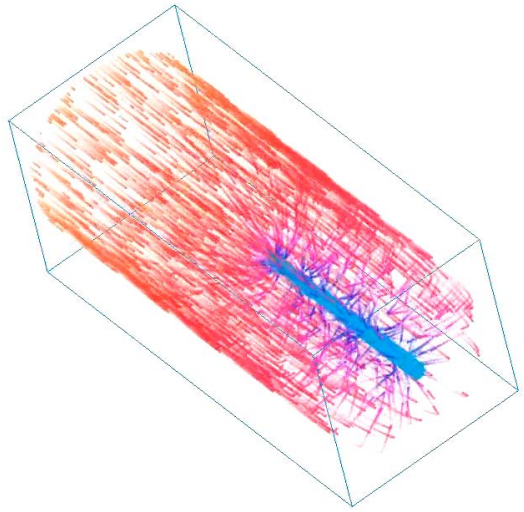






Summary, Conclusions, and Future Work

- Summary
  - Research program underway; interim results presented
  - 2 perforated cores have been analyzed with high-resolution CT techniques
  - Crushed zones characterized
- Conclusions
  - Integrated workflow validated / confirmed
  - Ability to control parameters that dictate cleanup level
  - Ability to resolve very small features (CZ < 1mm rem; pore structure)
- Future Work
  - Further analysis of these cores
  - Additional cores (different rocks – tight sandstones, carbonates, shales)
  - Varying levels of cleanup
  - Quantify perms
  - Simulate flow; interpret Section 4



QUESTIONS? THANK YOU

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