Numerical simulation of coupled fluid-solid interaction in digital rock samples

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COMSOL CONFERENCE
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Stanford
Rock Physics &
Borehole Geophysics Project

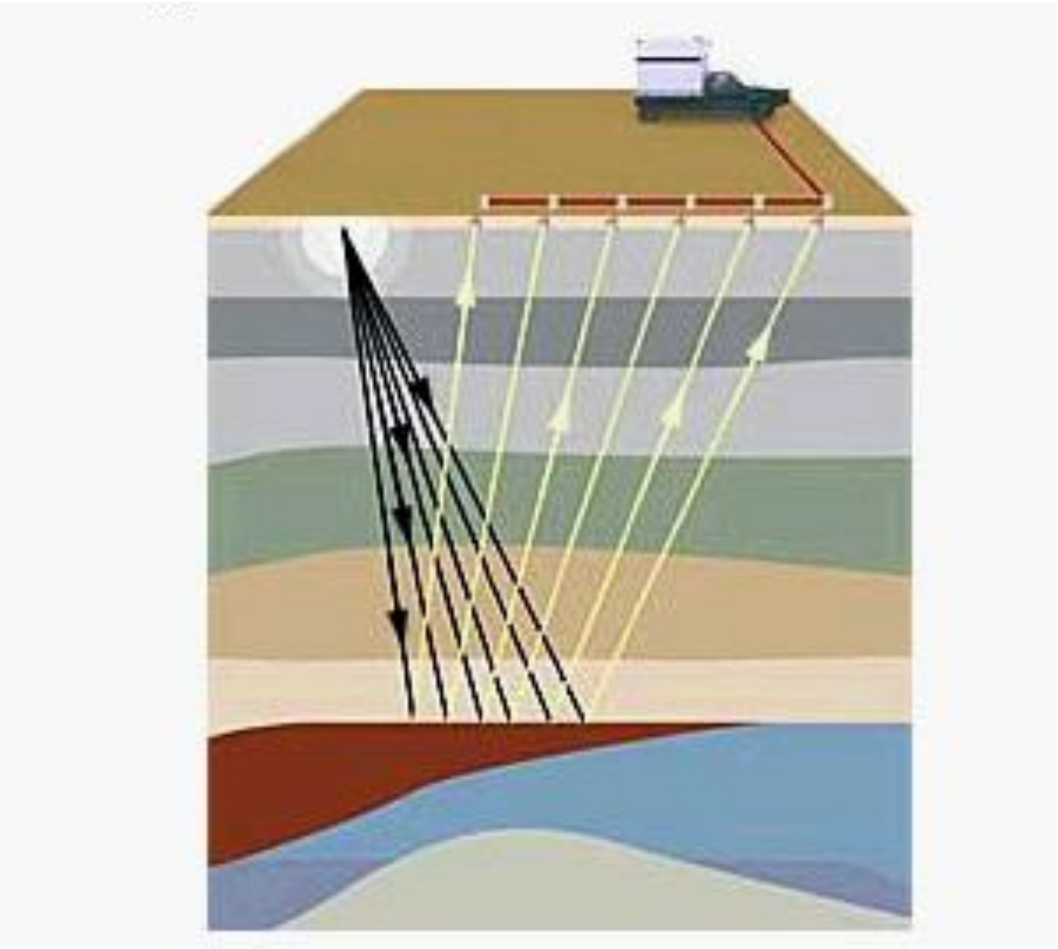
Understanding porous media important in many fields and applications

- Biosciences
- Material sciences
  - Batteries, fuel cells, filters
- Geosciences
- Food industry

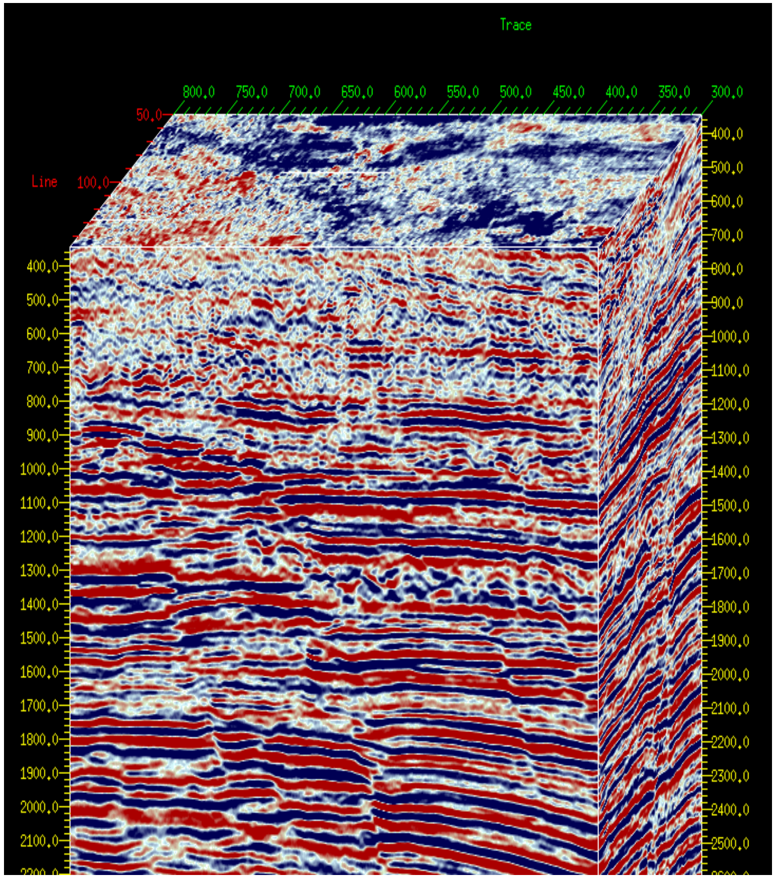
Need to understand the effective physical and transport properties of porous media

Understanding porous media in geosciences

Seismic field data acquisition

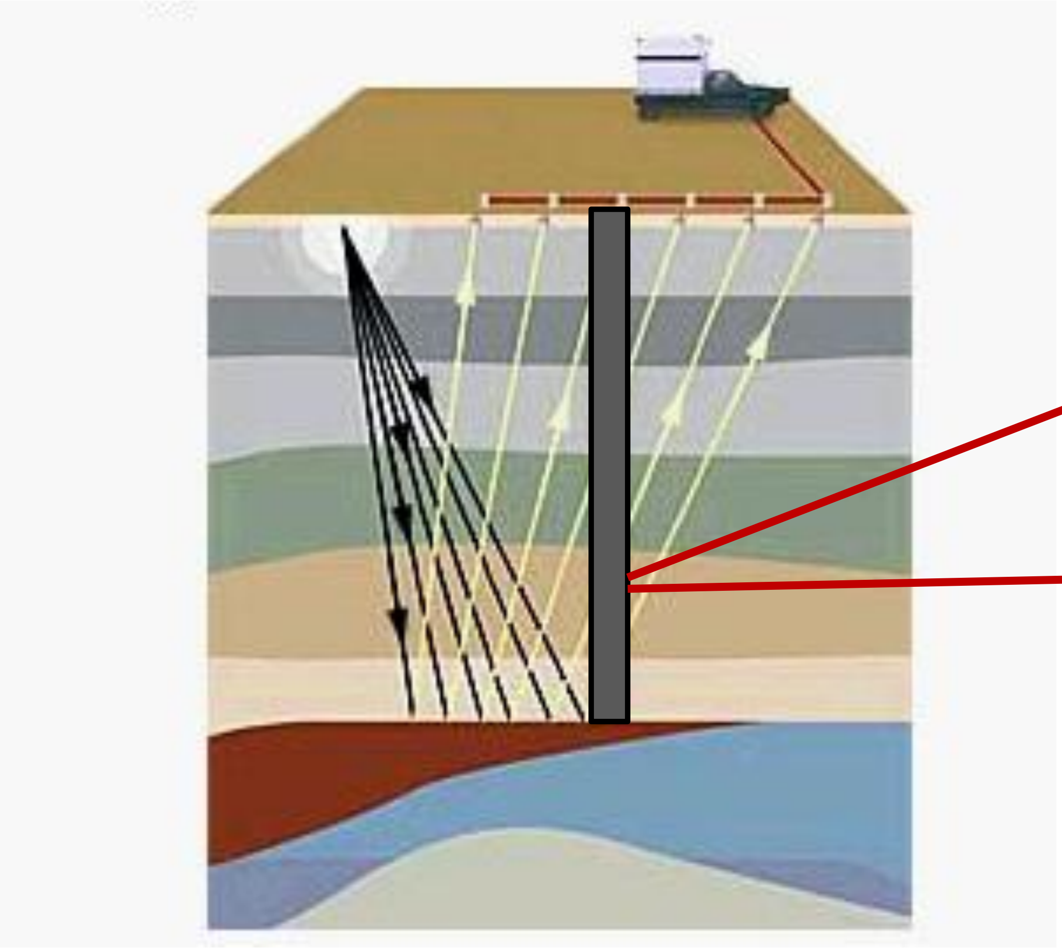


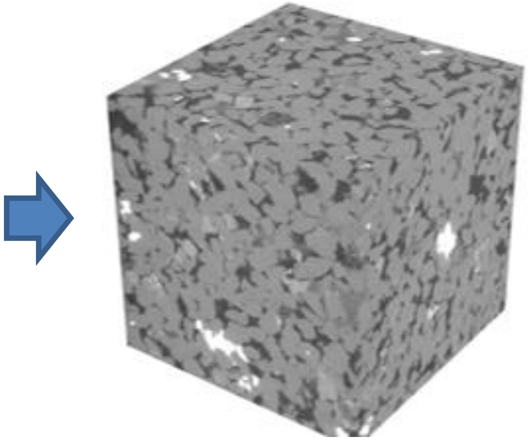
Seismic data



Understanding porous media in geosciences

Seismic field data acquisition



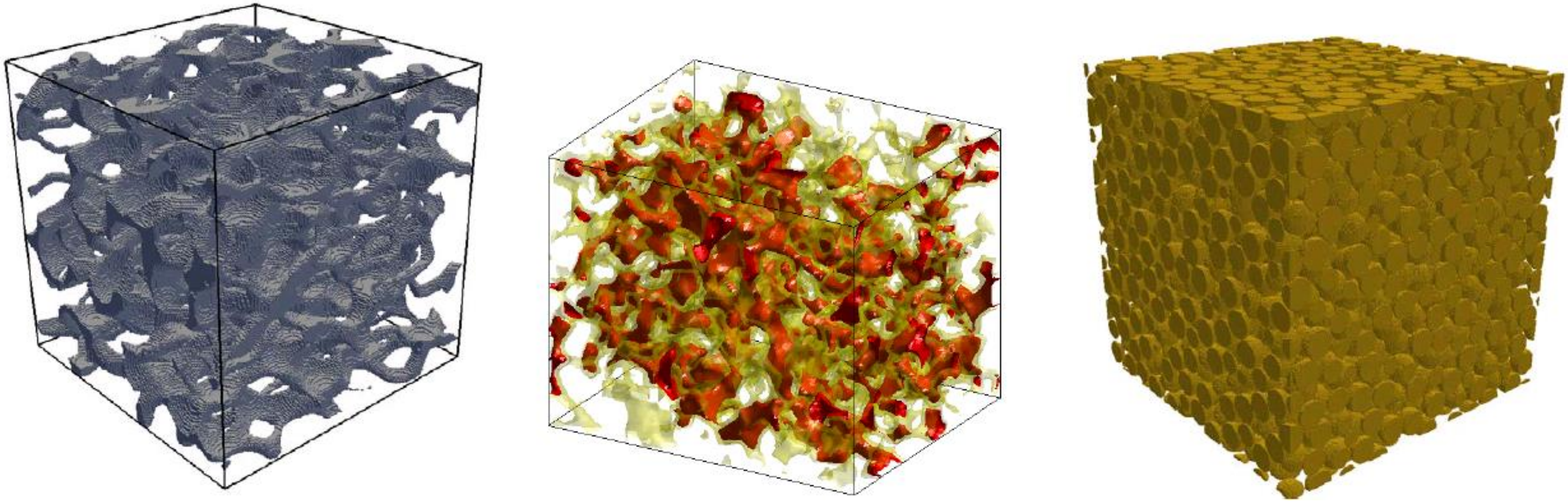


Digital Rock Physics (DRP)

Computational Multiphysics to handle:

complex microstructure

rigorous physics



Current challenges in DRP

Imaging

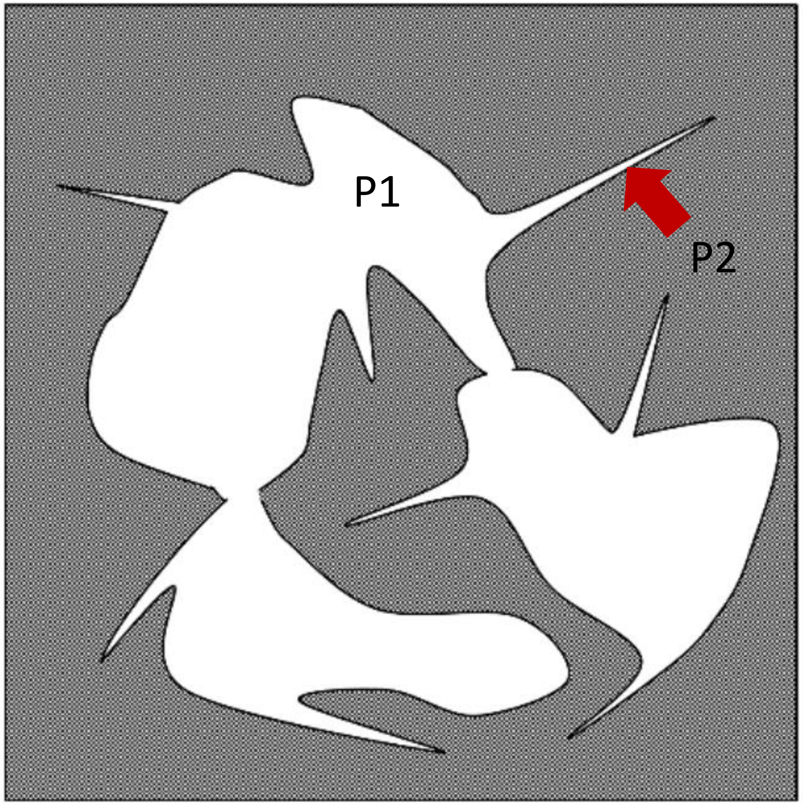
Processing

Simulating physics

Benchmarking

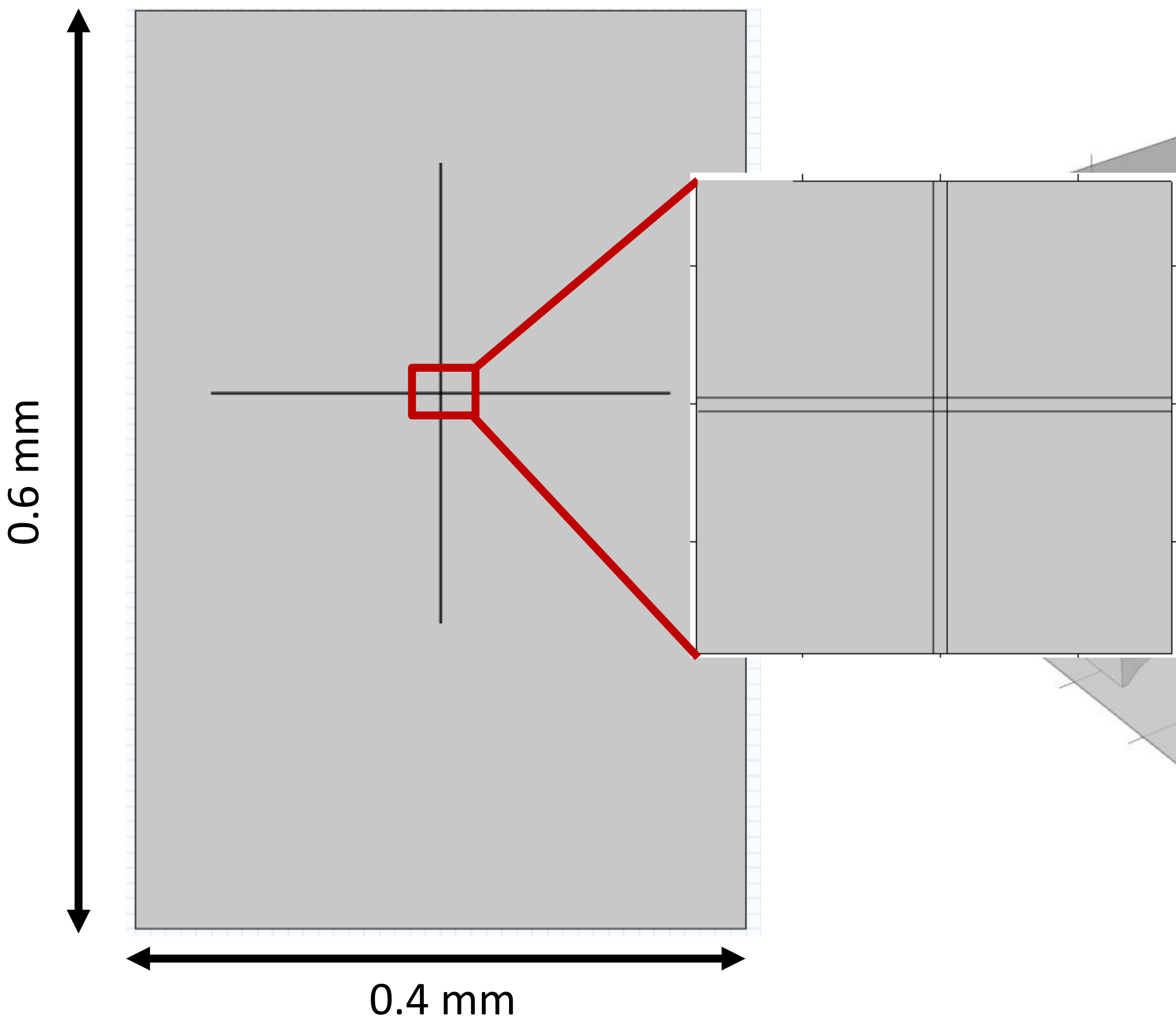
Motivation

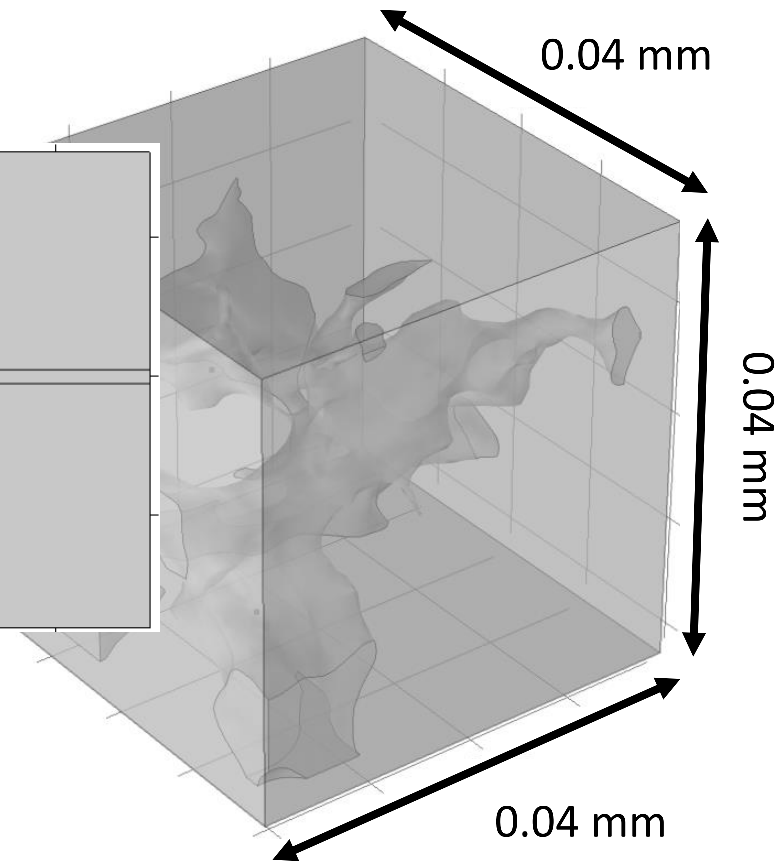
Simulate multiphysics related to dynamic coupled fluid-solid interaction effects at the pore scale



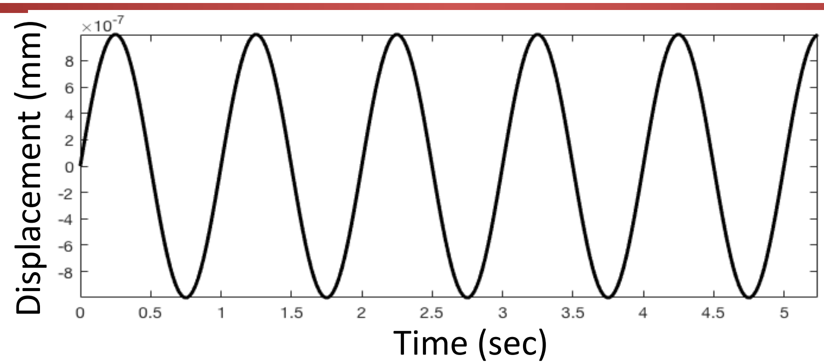
Numerical setup: Geometry

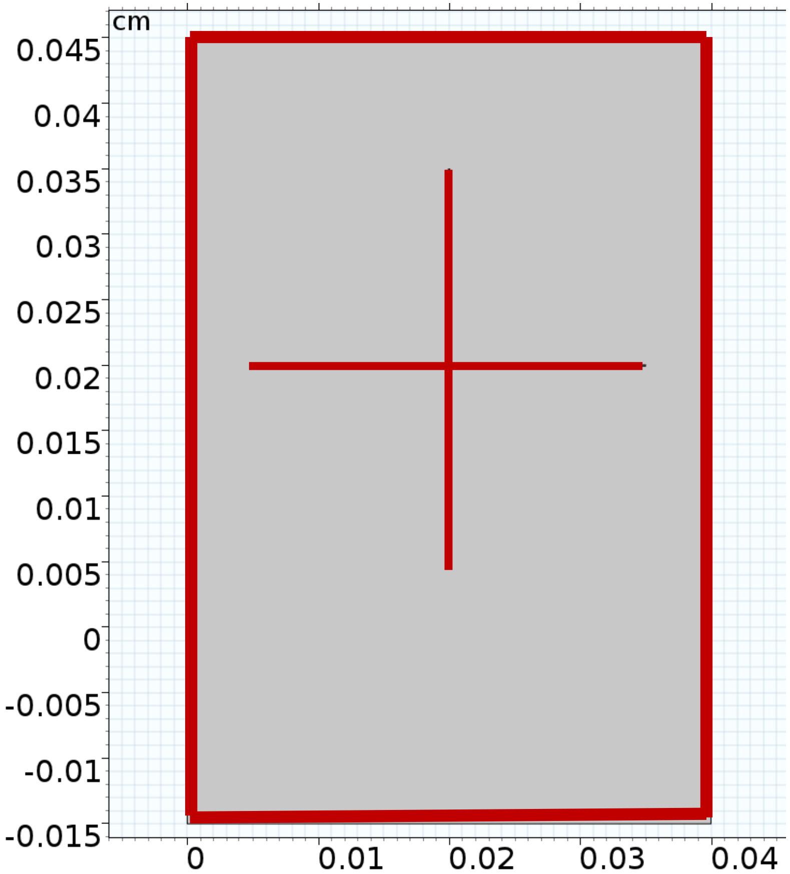
- 2D connected cracks
- 3D Berea µCT scan





Numerical setup: Boundary conditions



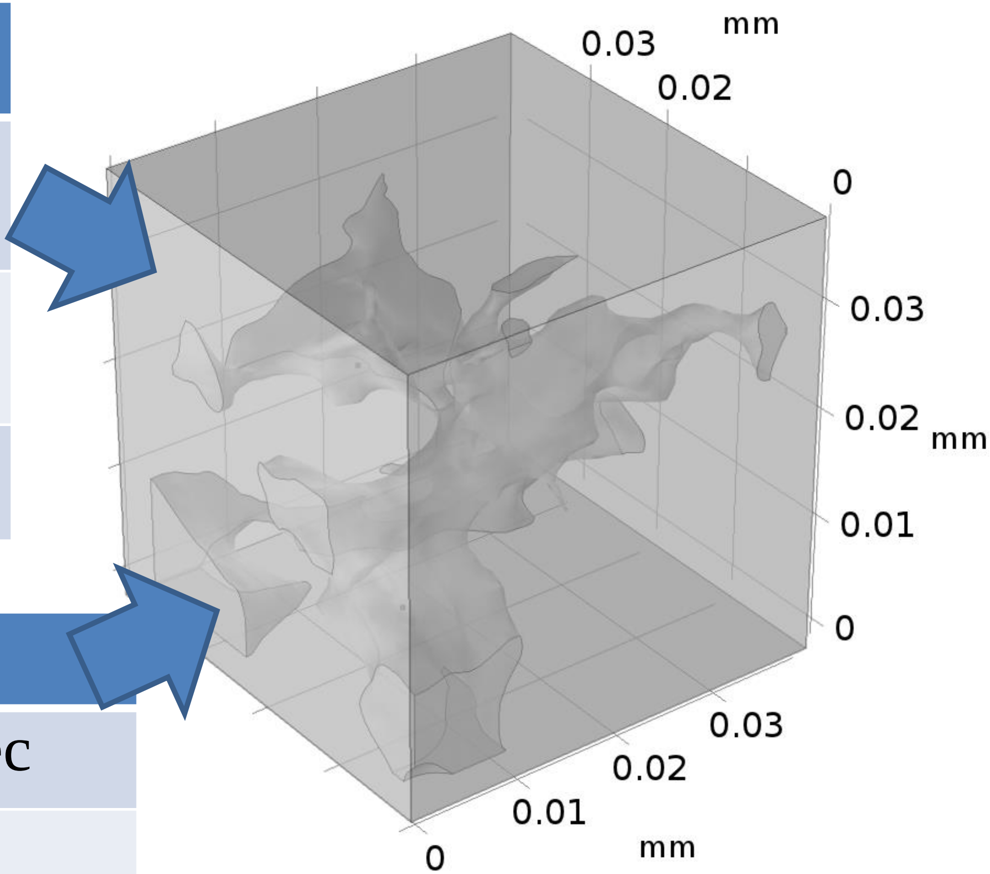


- Fixed constraint
- Roller constraint
- Sinusoidal displacement
- Solid displacement = fluid velocity at the interface (Coupling using Arbitrary Lagrangian-Eulerian (ALE) method)

Material properties

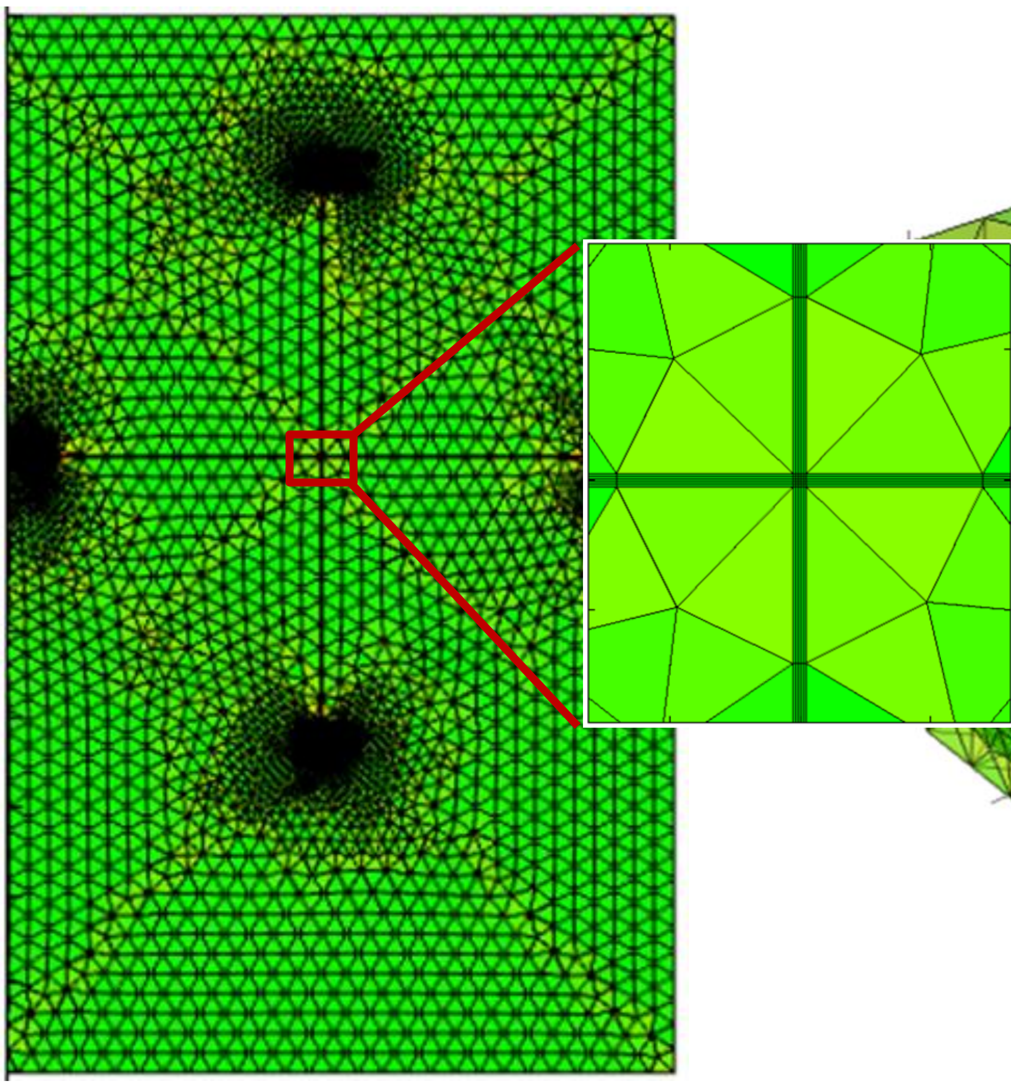
Grain	
Bulk modulus (K)	36.6 GPa
Shear modulus (μ)	45.5 GPa
Density (ρ)	2650 kg/m^3

Pore Fluid	
Viscosity (η)	0.486 Pa-sec
Reference Density (ρ_0) @ pressure (P_0) = 1 atm	860 kg/m^3
Bulk modulus (K_f)	1.02 GPa

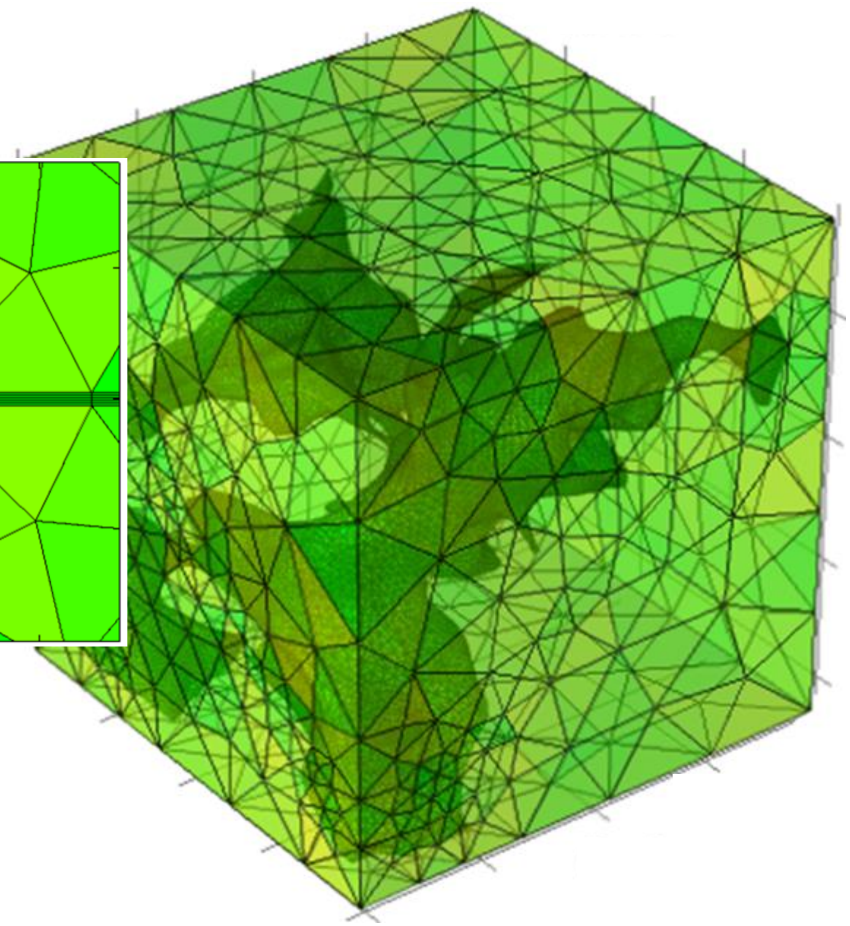


Numerical setup: Mesh

Total mesh elements ≈ 8000



Total mesh elements ≈ 327000



Numerical setup: Physics

- Conservation of mass and momentum

- Hooke's law for solid

$$\sigma_{ij} = \lambda\delta_{ij}\epsilon_{\alpha\alpha} + 2\mu\,\epsilon_{ij}$$

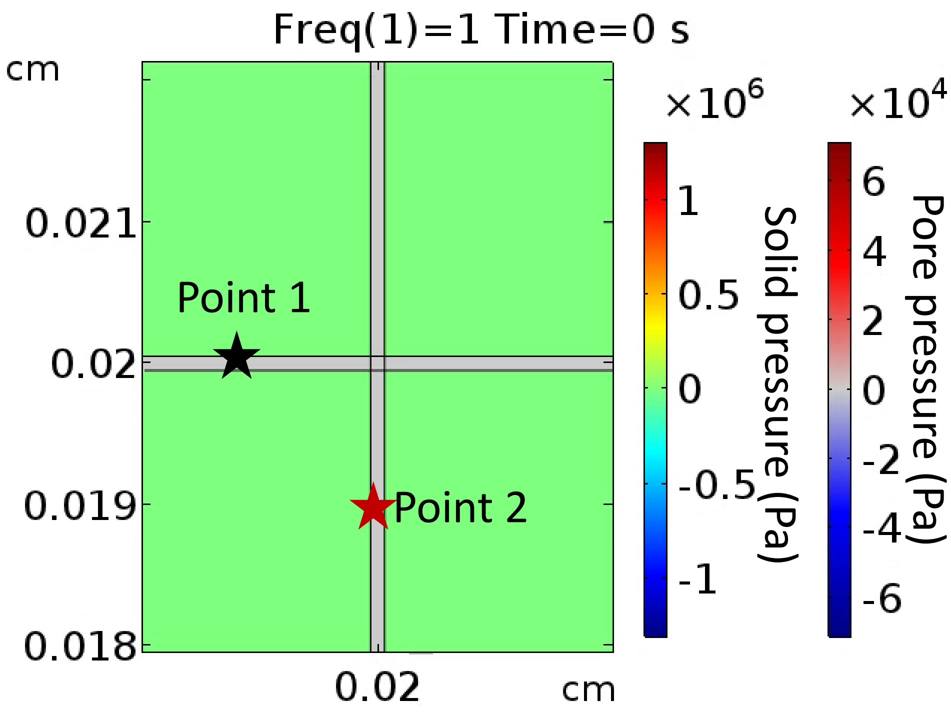
- Navier-Stokes' equation for compressible fluid

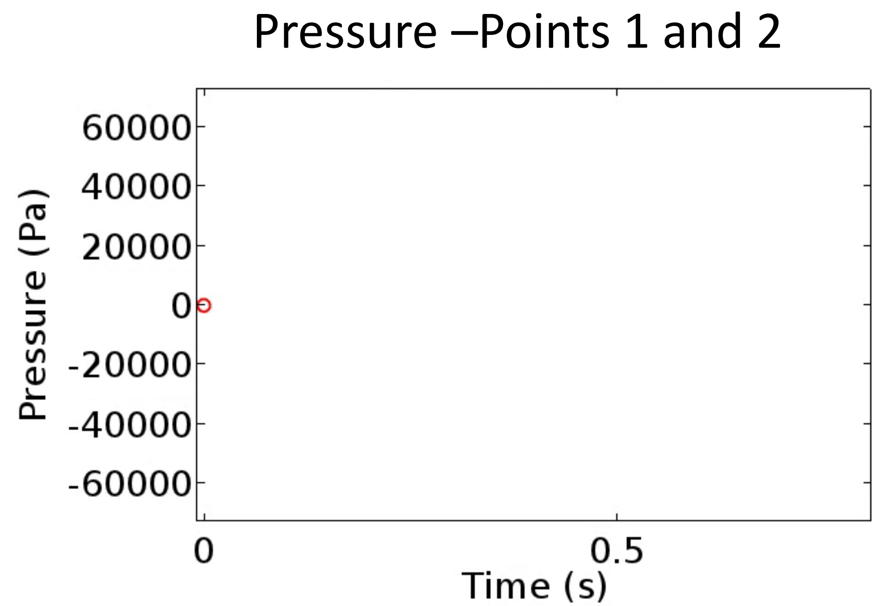
$$-\nabla p + \nabla.\left(\eta(\nabla u + (\nabla u)^T) - \frac{2}{3}\eta(\nabla.u)I\right) + F = \rho\frac{\partial u}{\partial t} + \rho u.\nabla u$$

- Variables solved for in solid – displacement
- Variables solved for in fluid – pressure and velocity

Results: 2D connected cracks (Relaxed)

- Frequency = 1 Hz (Relaxed state)





Results: 2D connected cracks (Relaxed)

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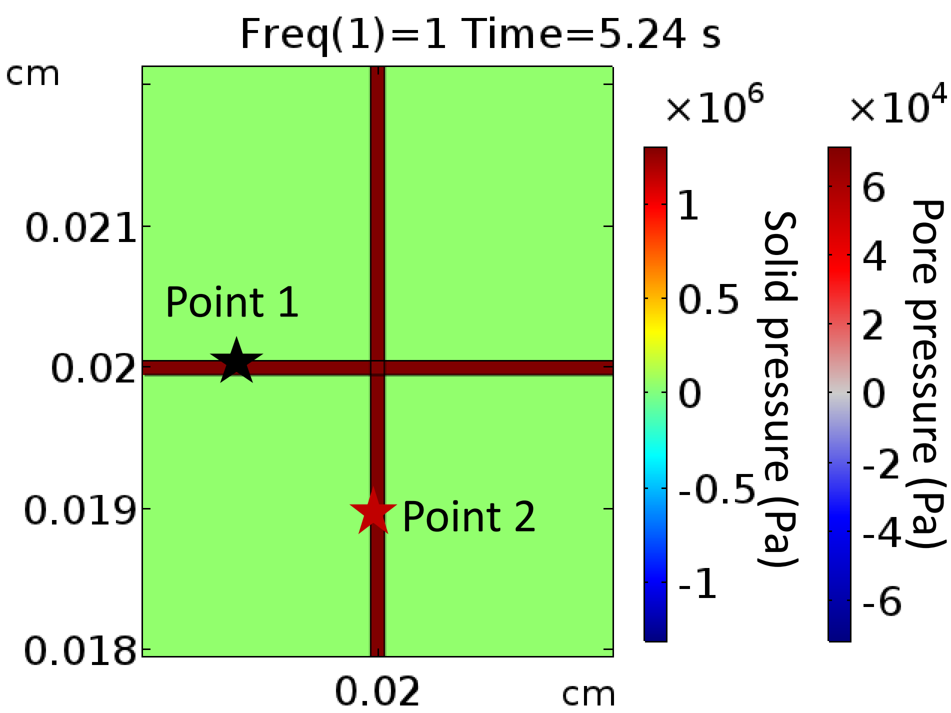
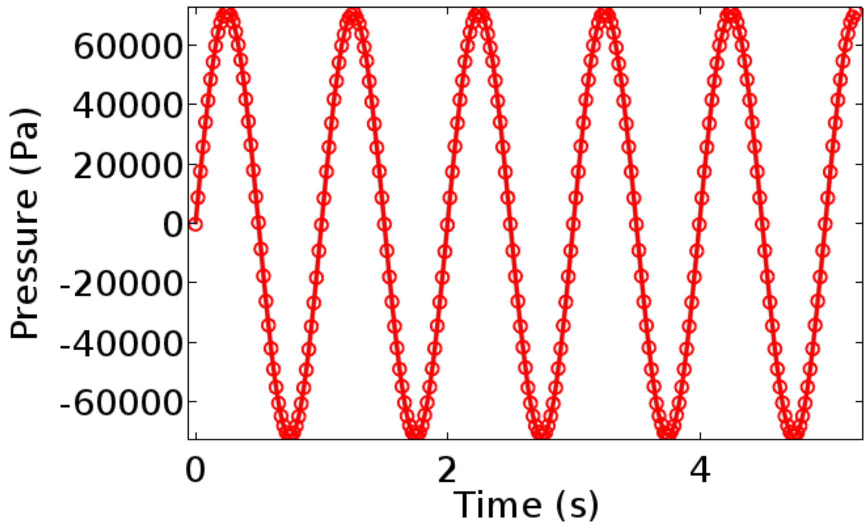
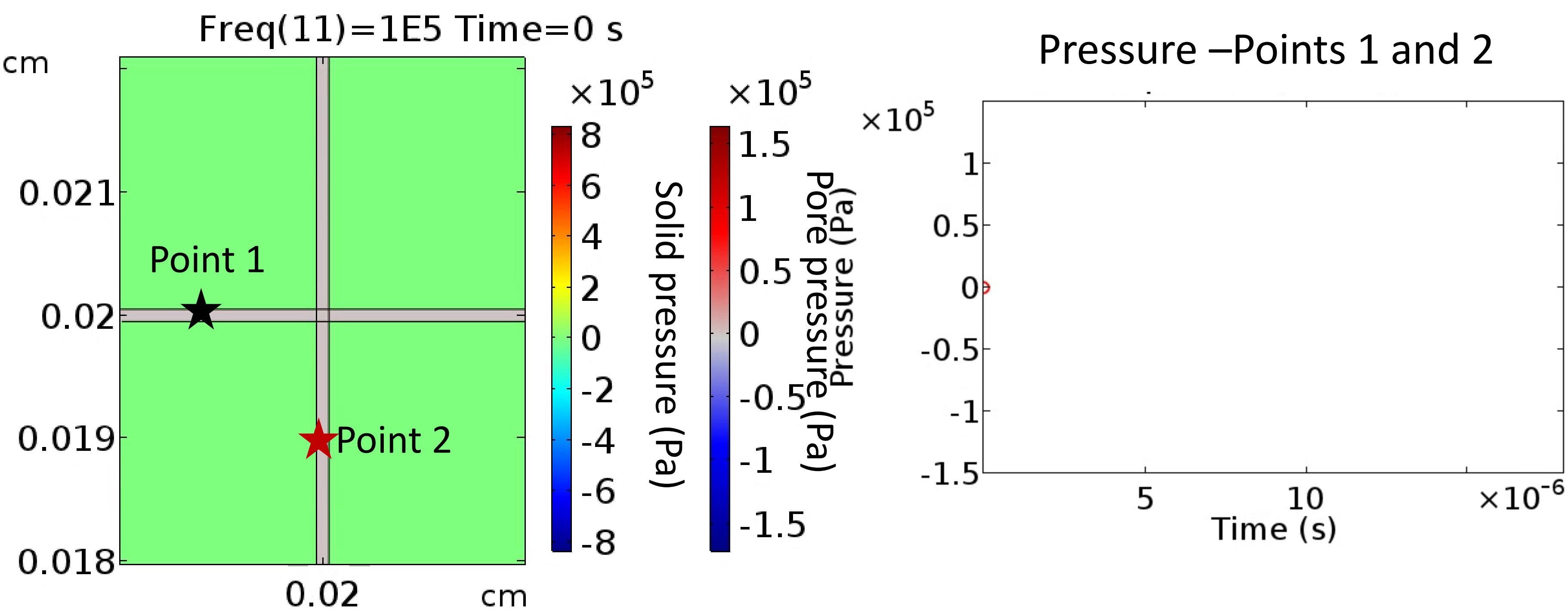


Pressure –Points 1 and 2



Results: 2D connected cracks (Unrelaxed)

- Frequency = 100 KHz (Unrelaxed state)



Results: 2D connected cracks (Unrelaxed)

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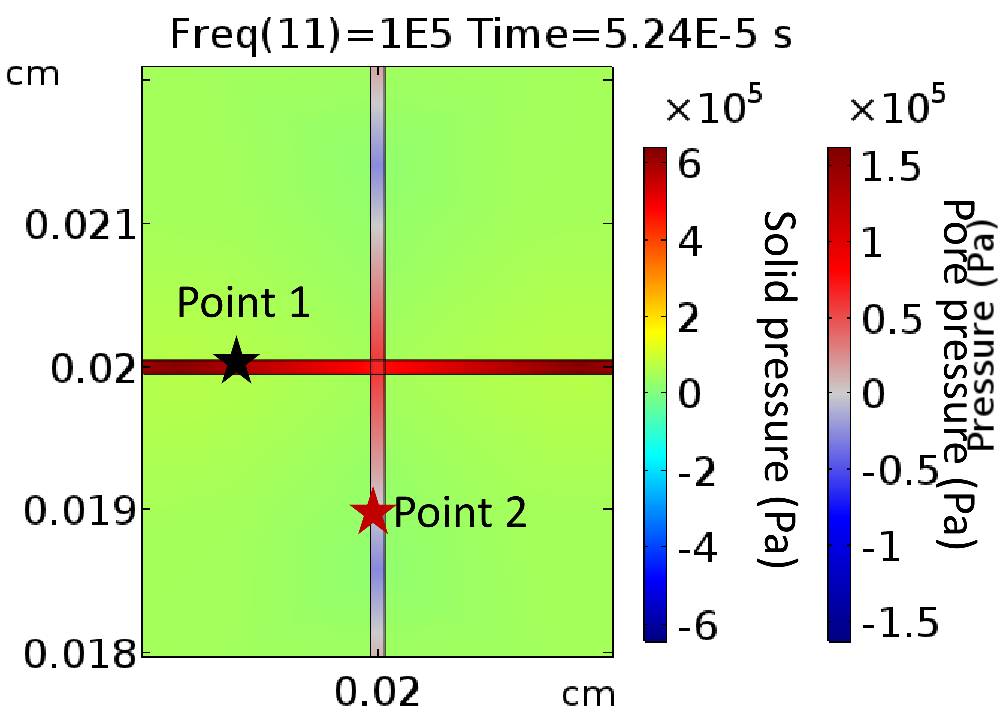
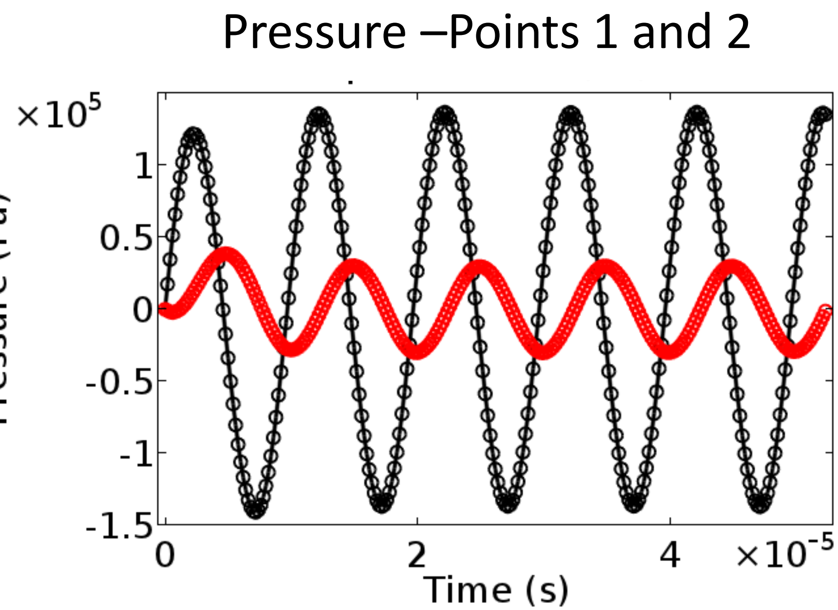
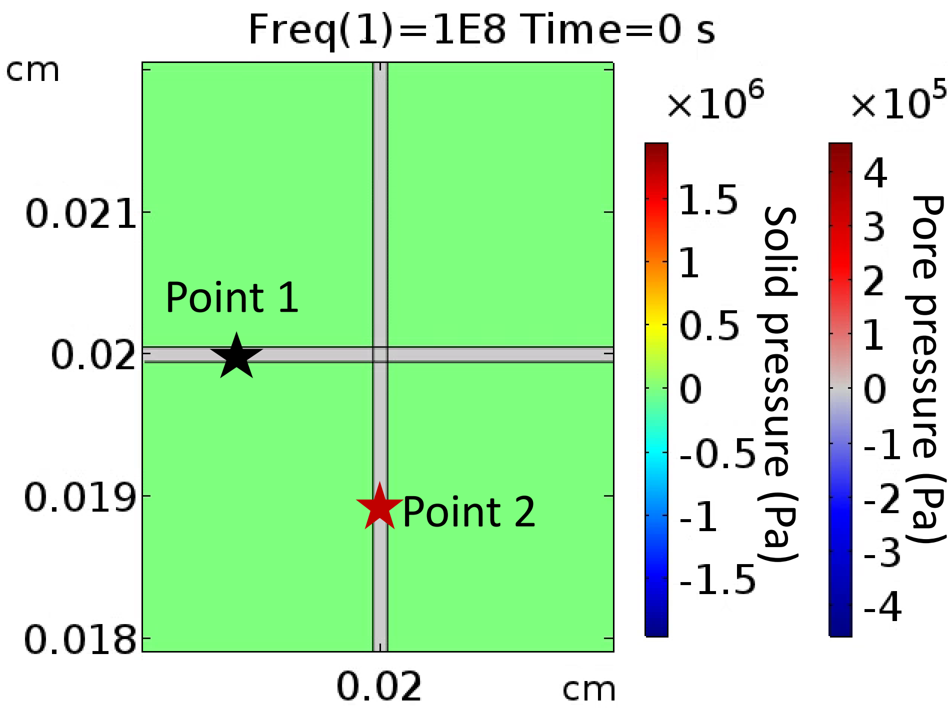
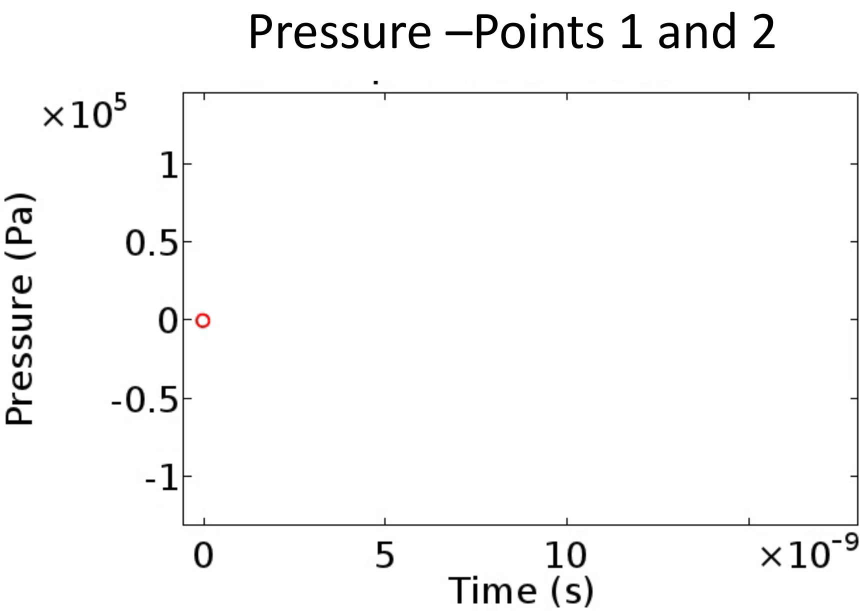




Results: 2D connected cracks (Scattering)

- Frequency = 100 MHz (Scattering)





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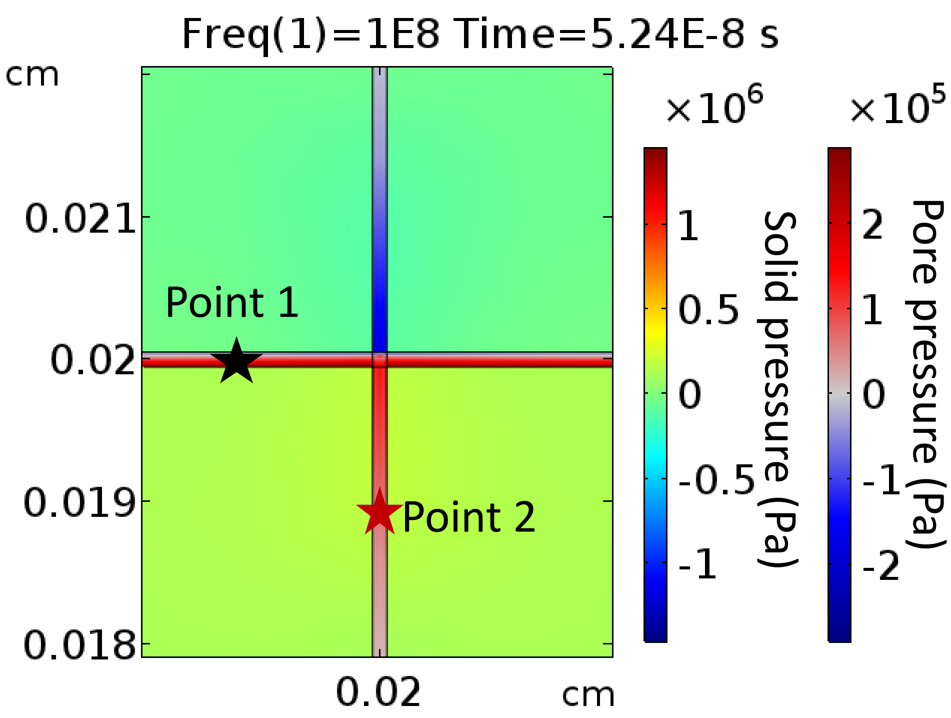
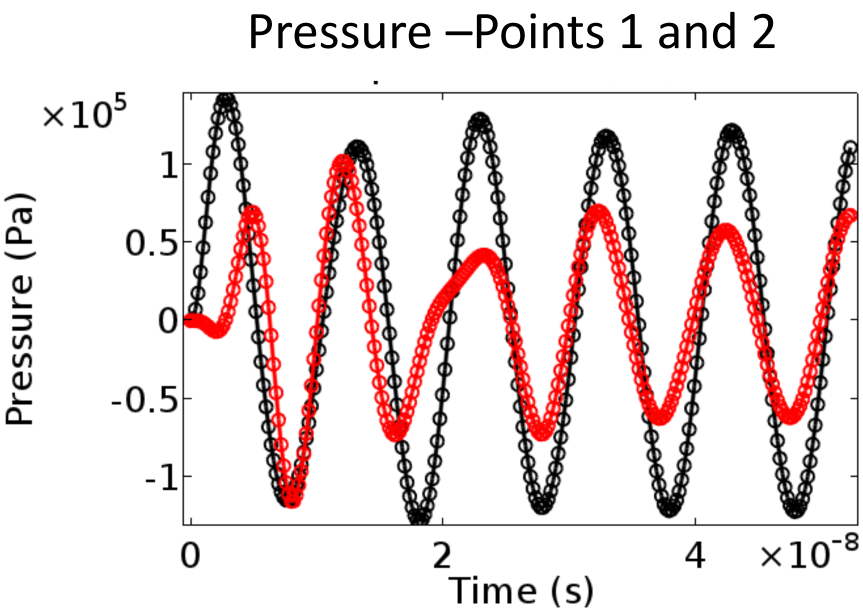
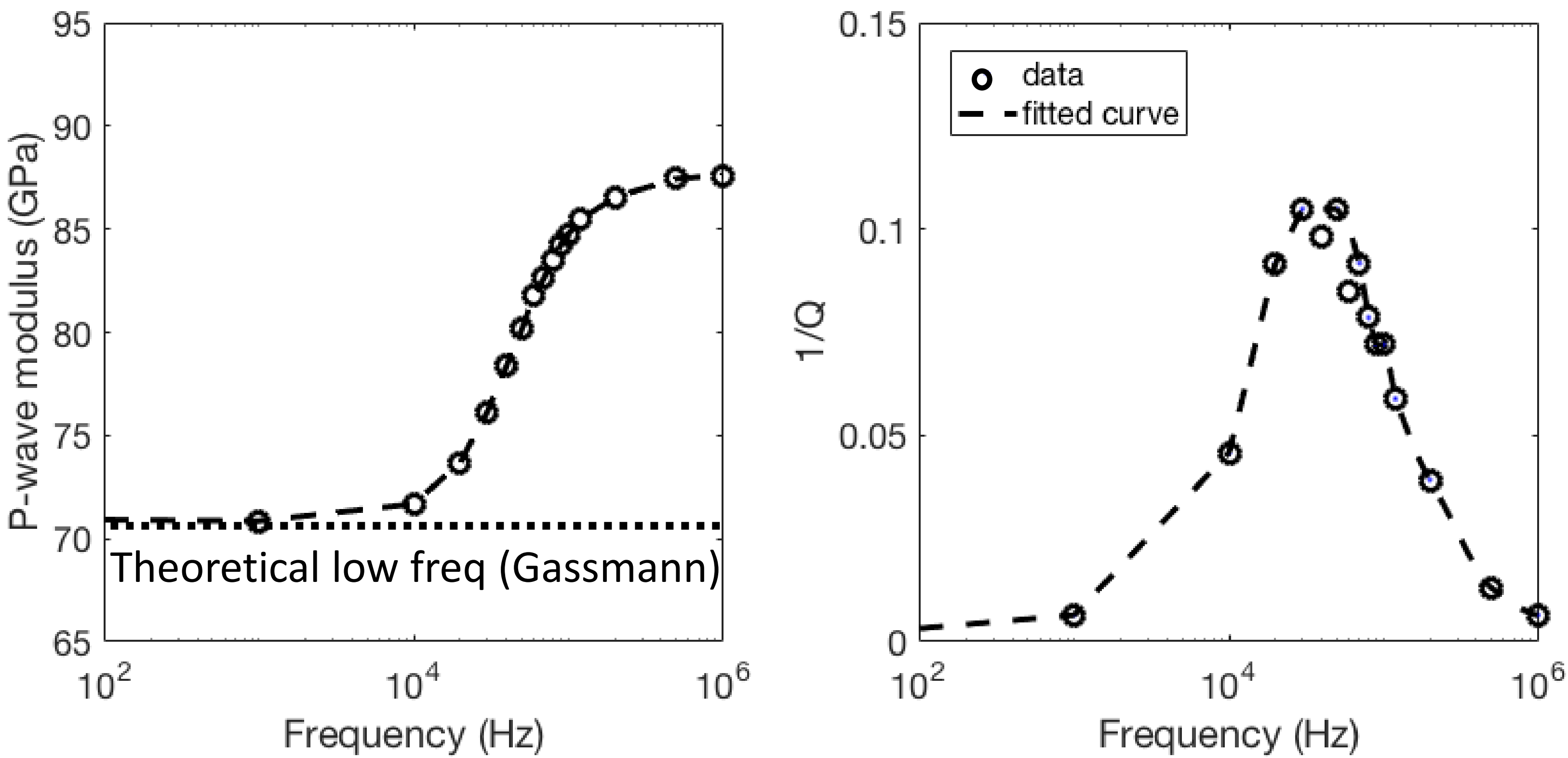




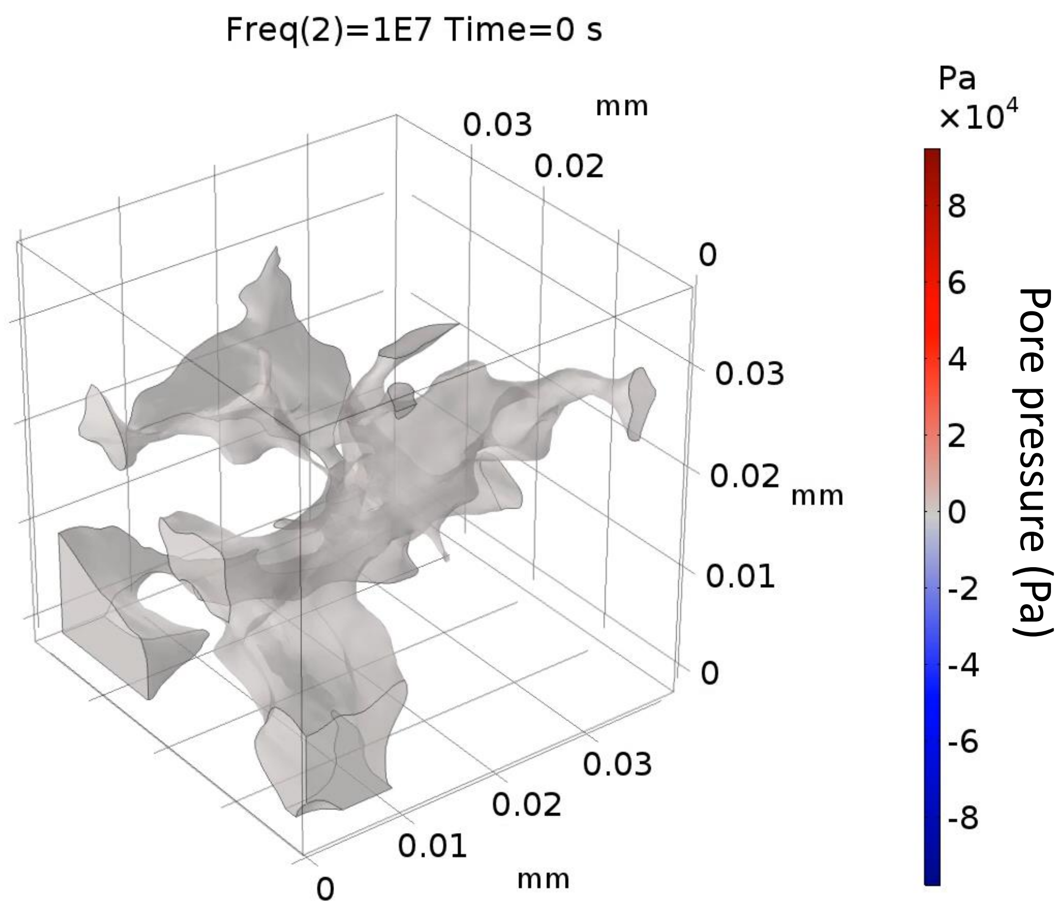
Results: 2D connected cracks

- Compressional modulus (M) and inverse Quality factor (1/Q)



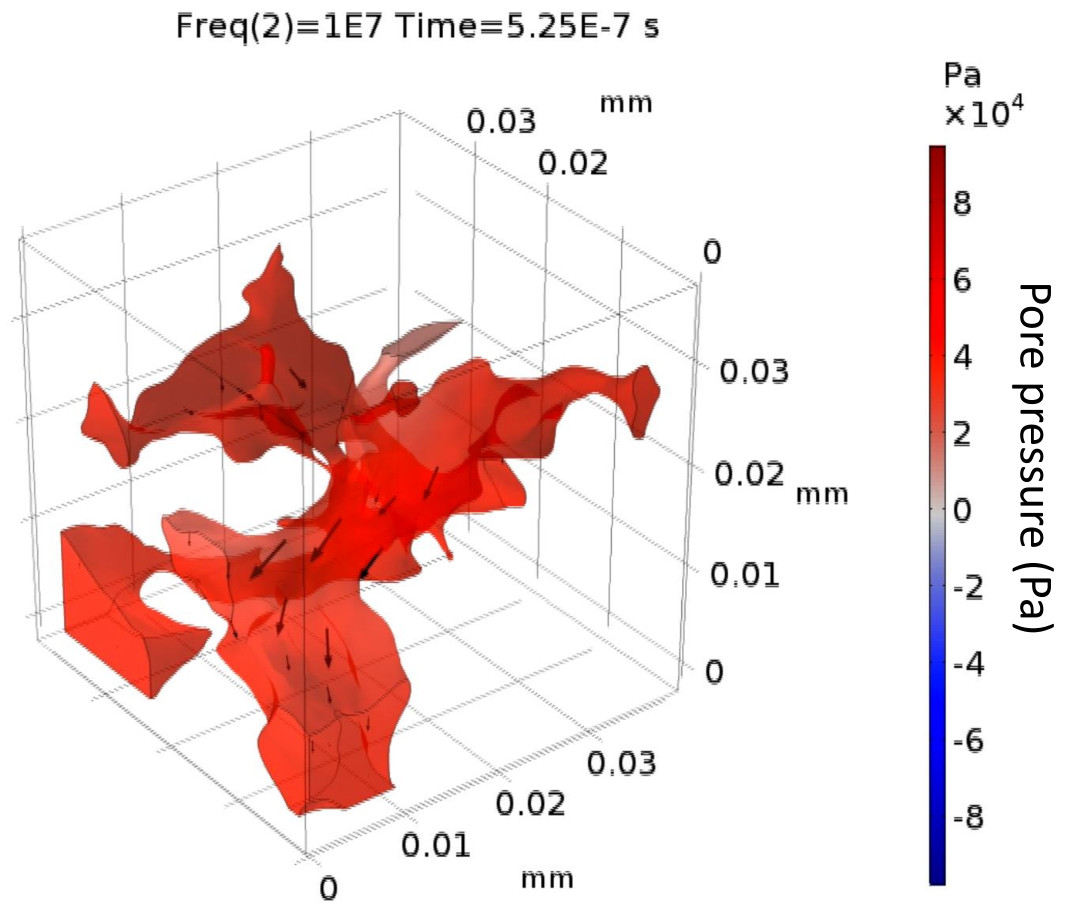
Results: 3D Berea (Unrelaxed frequency)

- Frequency = 10 MHz (Unrelaxed state)



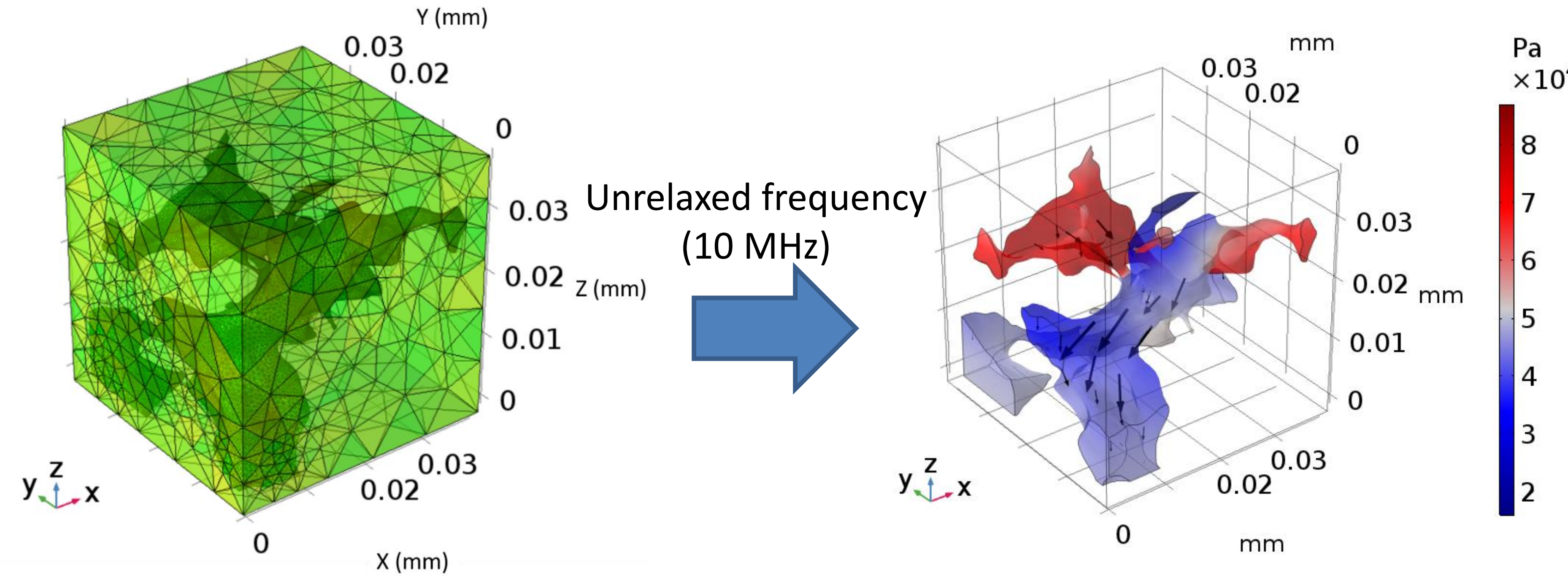
Results: 3D Berea (Unrelaxed frequency)

- Frequency = 10 MHz(Unrelaxed state)



Conclusion

- Fluid related dispersion modeled on digital rock samples using COMSOL's FSI module



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