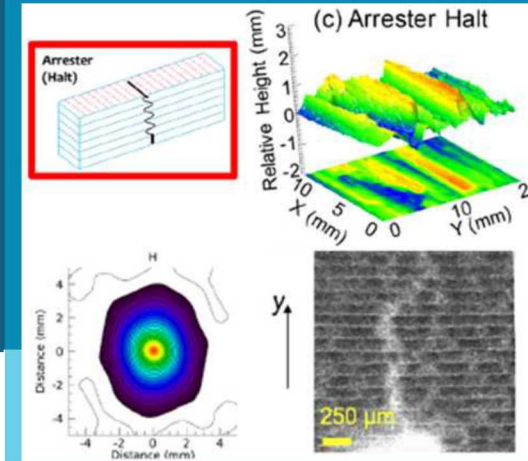
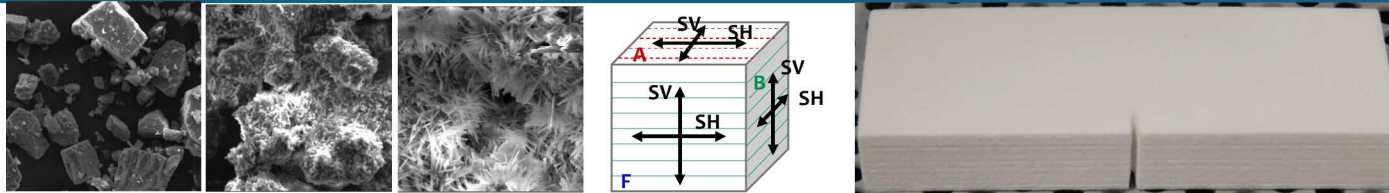


Geomechanical Characterization of Gypsum-Based 3D Printed Materials



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Geomechanics Department
Sandia National Laboratories, NM

Collaborators:
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Liyang Jiang, Laura Pyrak-Nolte, Antonio Bobet (Purdue Univ.)

This work was supported by the Laboratory Directed Research and Development program at Sandia National Laboratories.

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- Motivations & 3D Printing of Geomaterials
- Mechanical Testing of Geo-architected Rocks



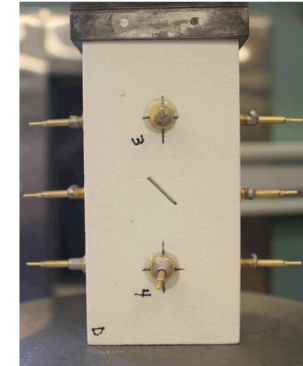
3D printing for Geoscience Applications

◆ Why 3D printing?

- Develop methodology for additive manufacturing of synthetic materials that **mimic** natural materials
- Overcome sample-to-sample variability for testing material response
- Connect controllable structures (e.g., fracture, bedding direction) to macro-scale behavior to advance constitutive models for poro-hydro-mechanics

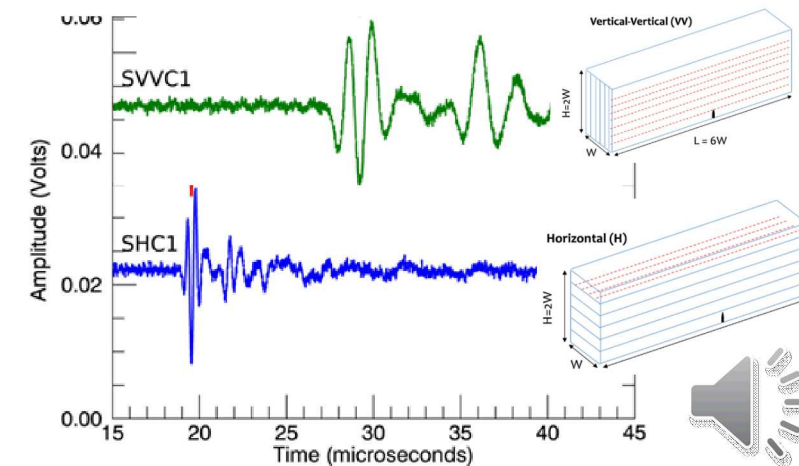
◆ Geo-architected Rock

- A rock analog that is fabricated and structured using conventional or unconventional methods to develop controlled features in specimens for repeatable experimental behavior
- **Mineral texture and orientation of anisotropy related to geomechanical properties**
- Integrated geomechanical and geophysical measurement with microCT imaging and digital image correlation for fracture mechanics

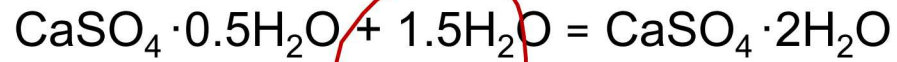


Printed gypsum sample with single flaw geometry with AE sensors

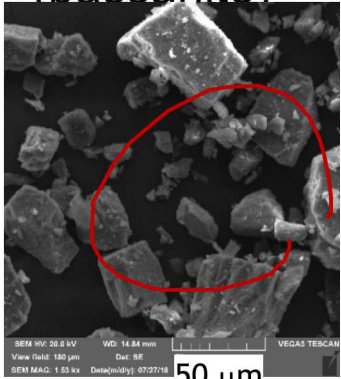
Anisotropic samples with acoustic waveforms



Powder Based 3D printing: Reaction-Driven Transformation Process



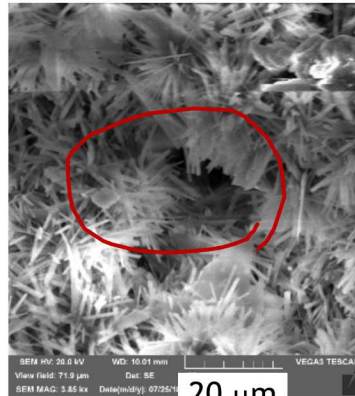
Powders
(bassanite)



Powders

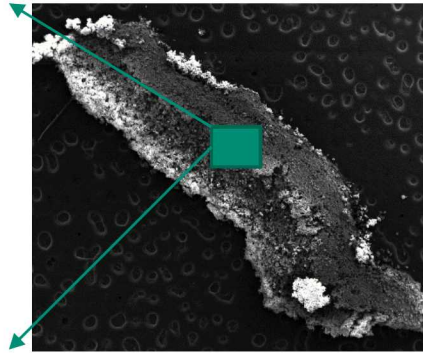
Binder

Gypsum



Reaction products

1 mm

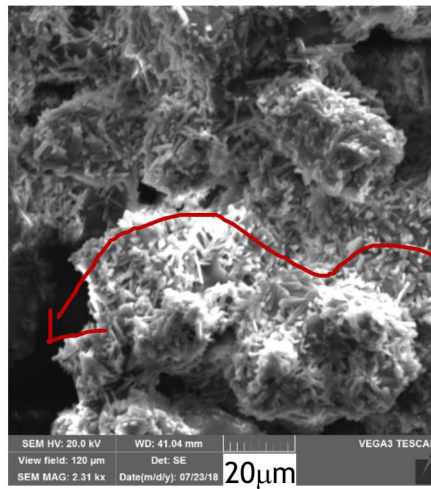
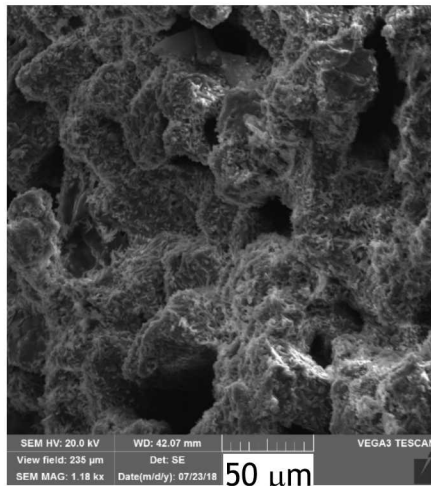


Layer thickness = 100 μm

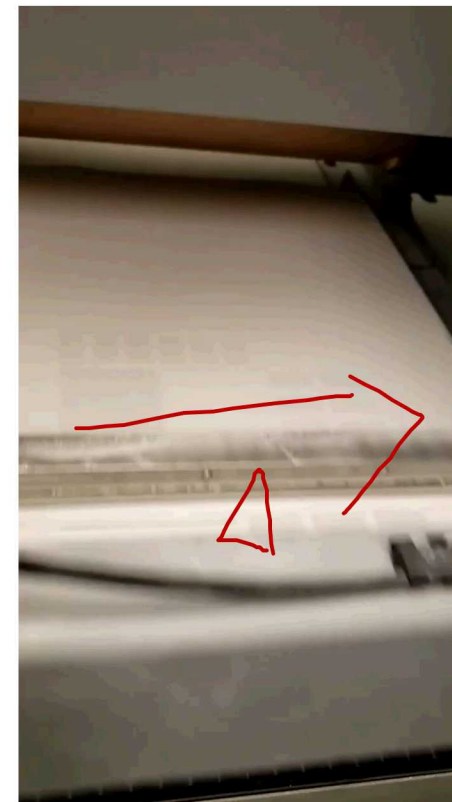
Two major principal directions:

1. **Depositional (vertical)**
2. **Binder spreading (horizontal)**

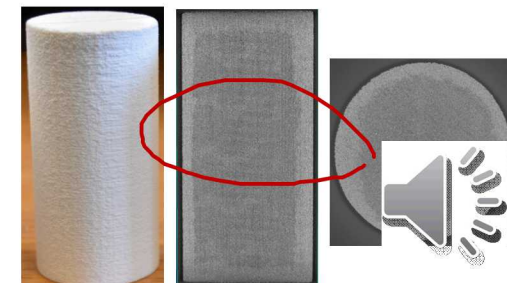
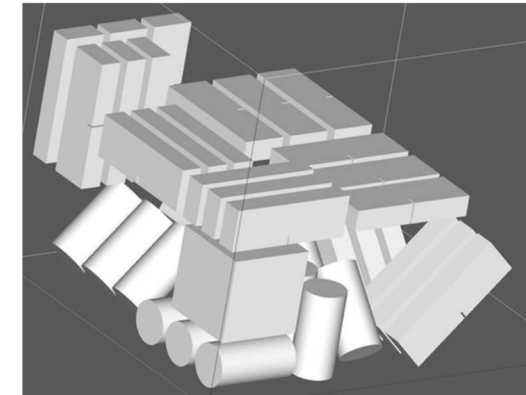
A mix of large conglomerated grains and rod shape gypsum



ProJet 360/460

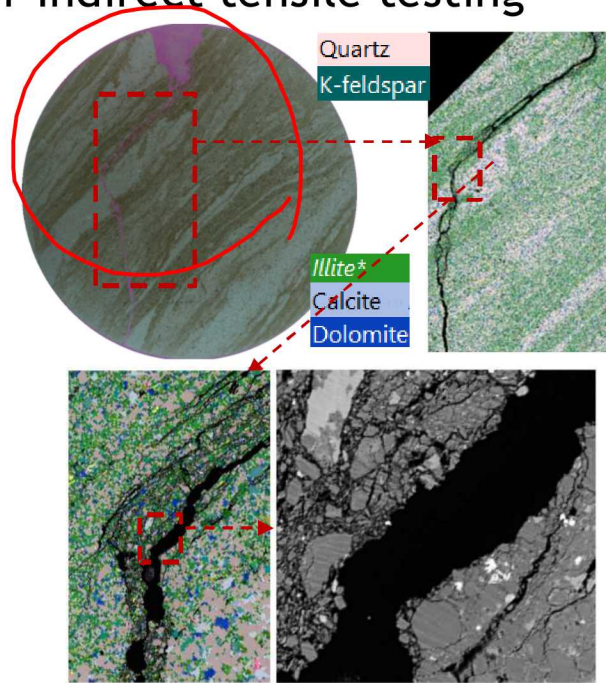


A batch of
3D printing samples

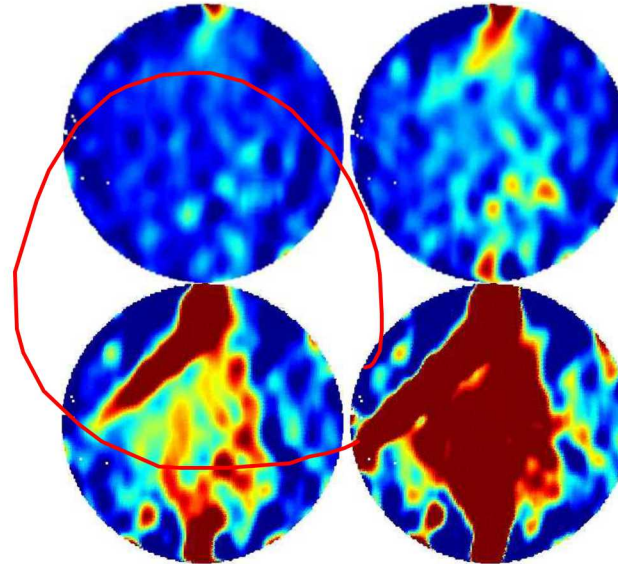


Observations of Fracture Resistance in Layered Geological Media

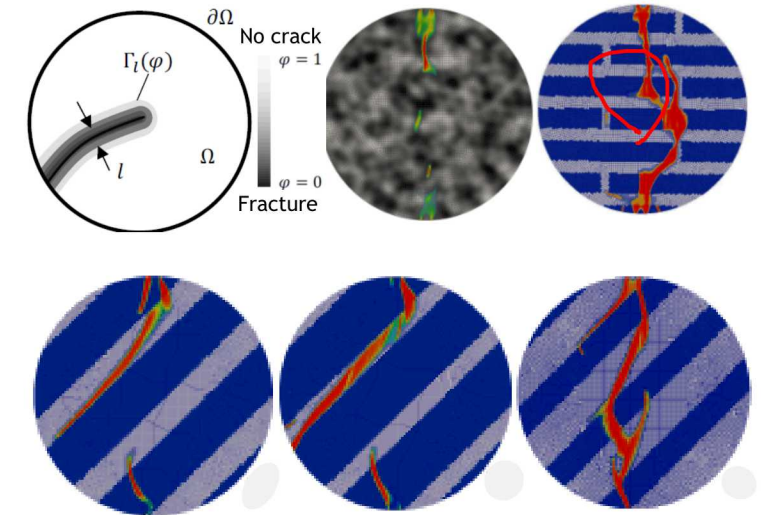
A. A thin section of Mancos shale after Indirect tensile testing



B. Lateral strain based on digital image correlation measurements



C. Phase field modeling results (crack initiation & propagation)

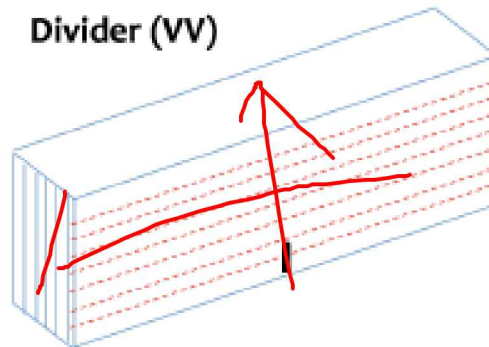


Na et al. (2017, JGR, 122(8), 6202-6230); Yoon et al. (2020, AAPG Memoir 120, Chapter 8)

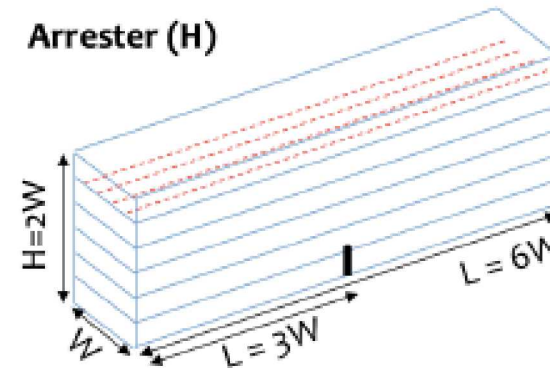
3 point bending samples

— Depositional direction
- - - Binder spray direction

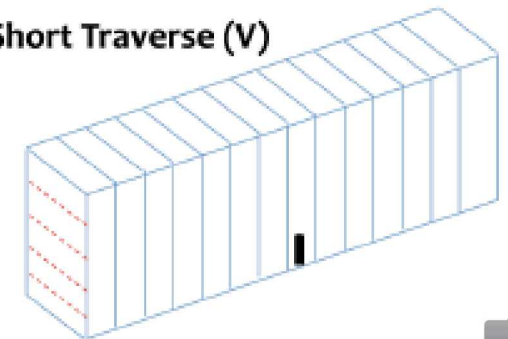
Divider (VV)



Arrester (H)



Short Traverse (V)



Jiang et al. (2020, Scientific Reports)



- Motivations & 3D Printing of Geomaterials
- Mechanical Testing of Geo-architected Rocks

- *Material Properties*

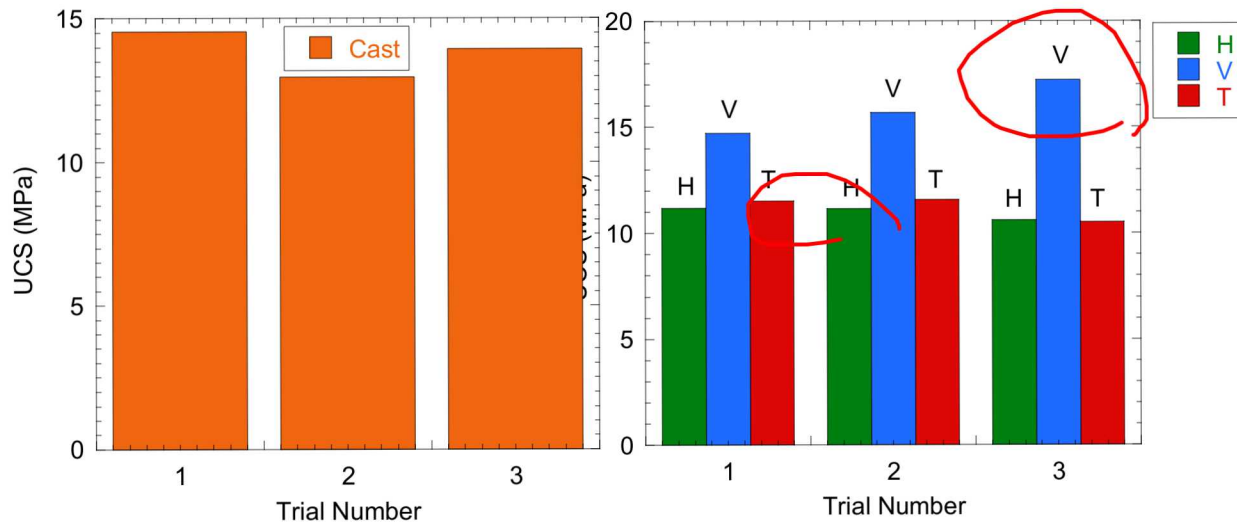
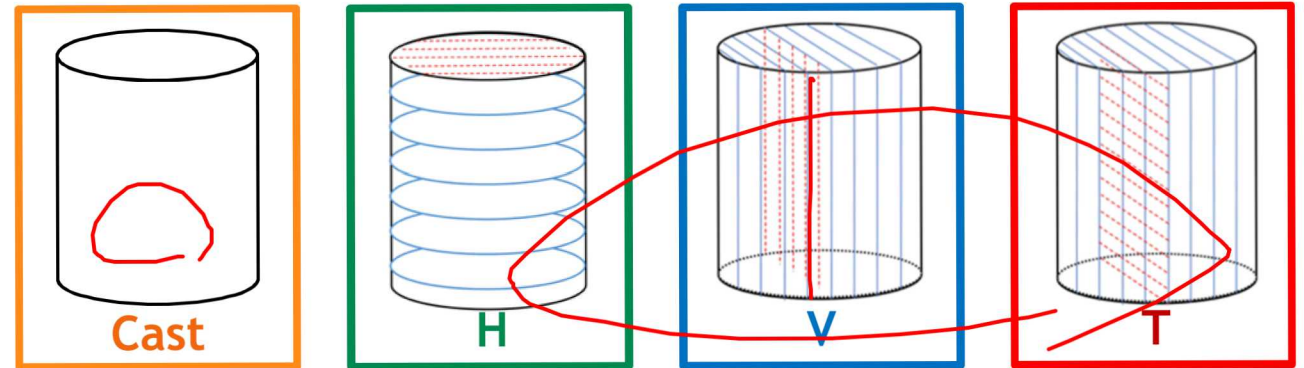
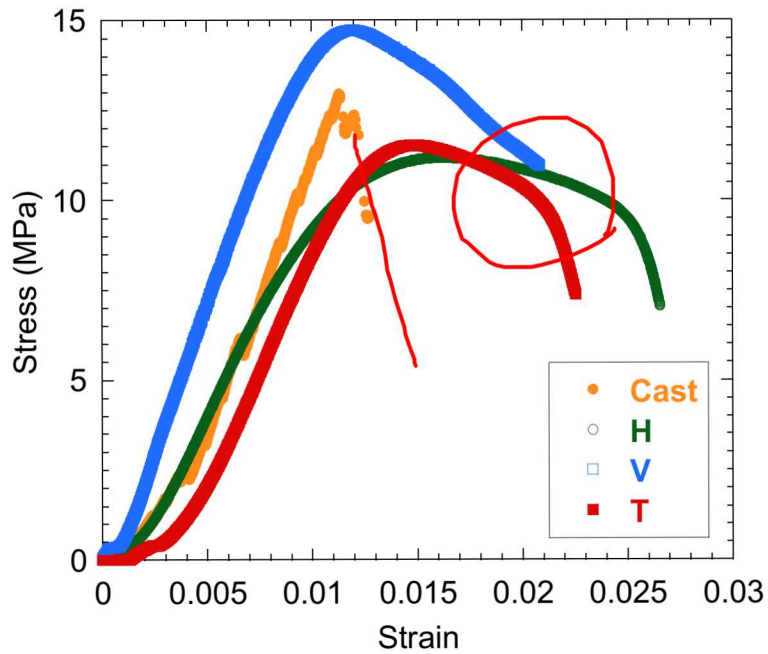
- *Unconfined Compressive Strength (UCS) Test*

- *Ultrasonic Compressional & Shear Wave Measurements*

- *Tensile Failure - Three Point Bending (3PB) Test*

Jiang, L., Yoon, H., Bobet, A., Pyrak-Nolte, L.J. Mineral Fabric as a Hidden Variable in Fracture Formation in Layered Media. *Sci Rep* 10, 2260 (2020). <https://doi.org/10.1038/s41598-020-58793-y>

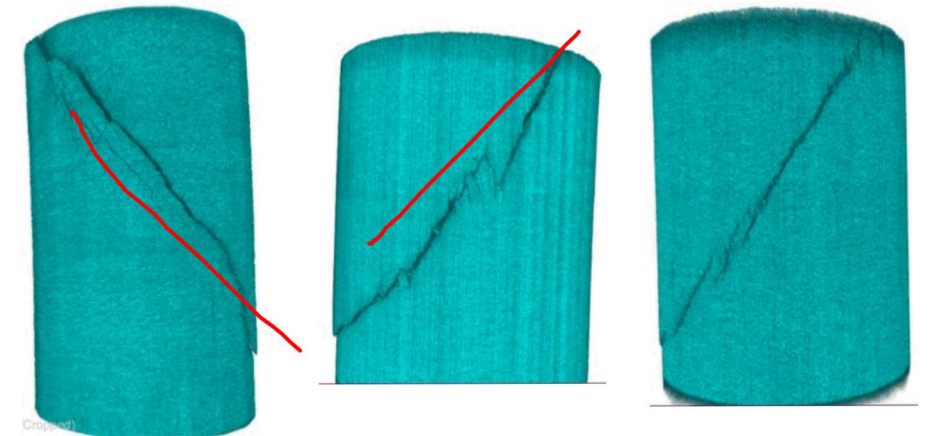




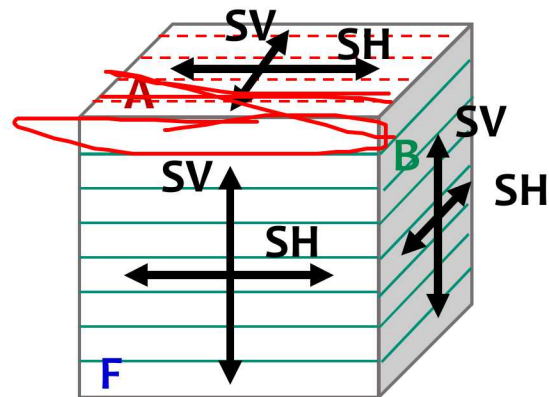
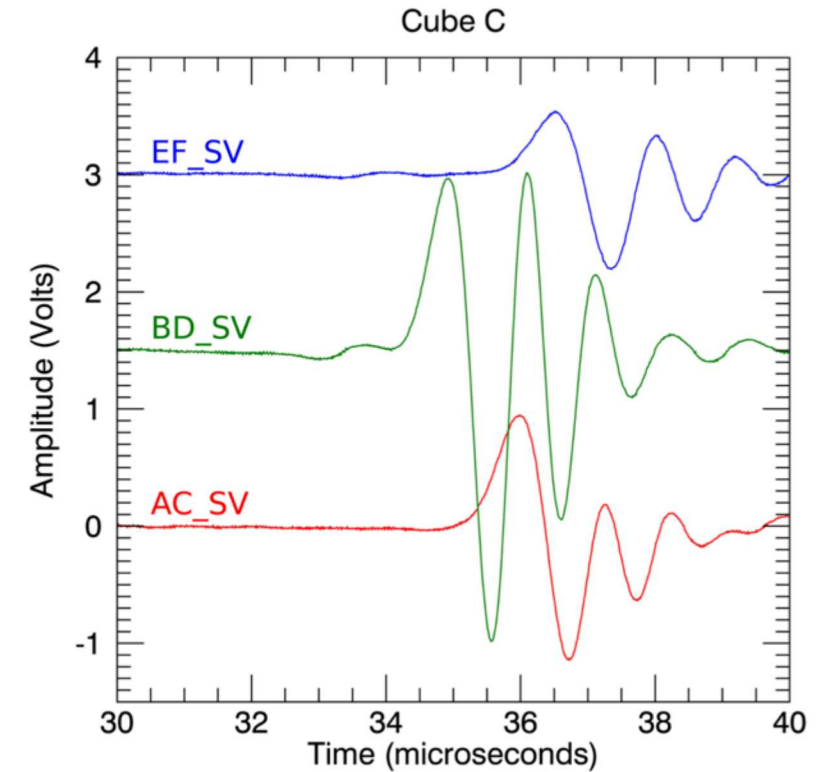
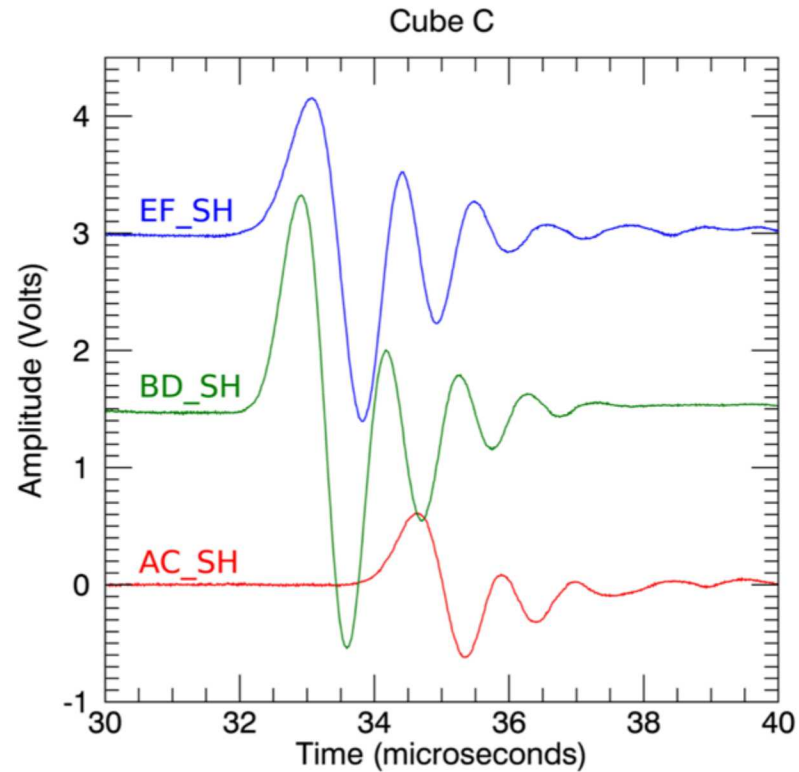
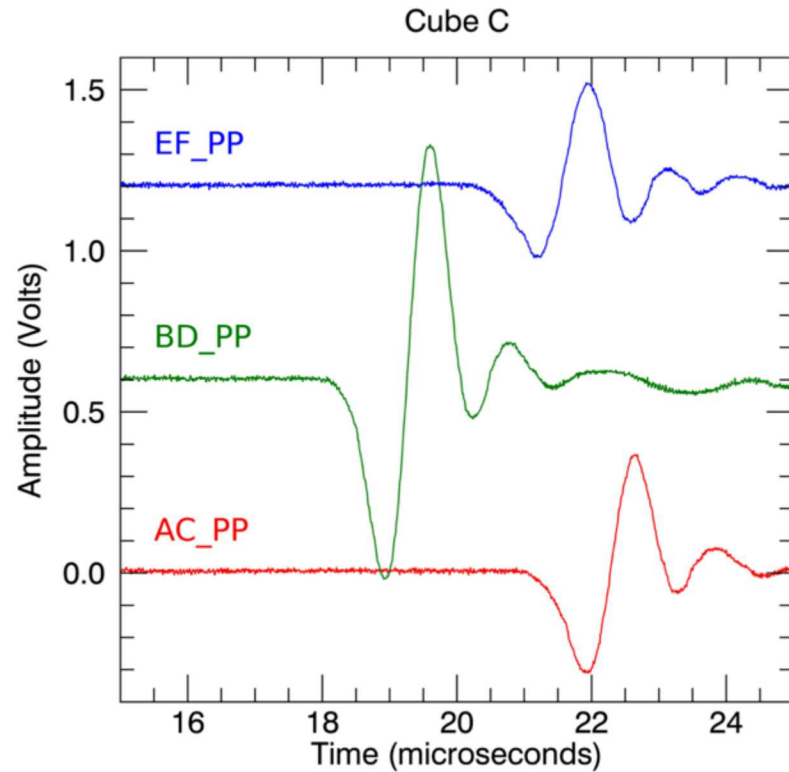
Photo



X-ray Computed Tomographic Reconstructions



Observation of Seismic Anisotropy in 3D Printed Samples

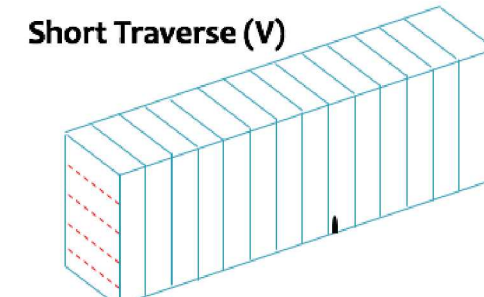
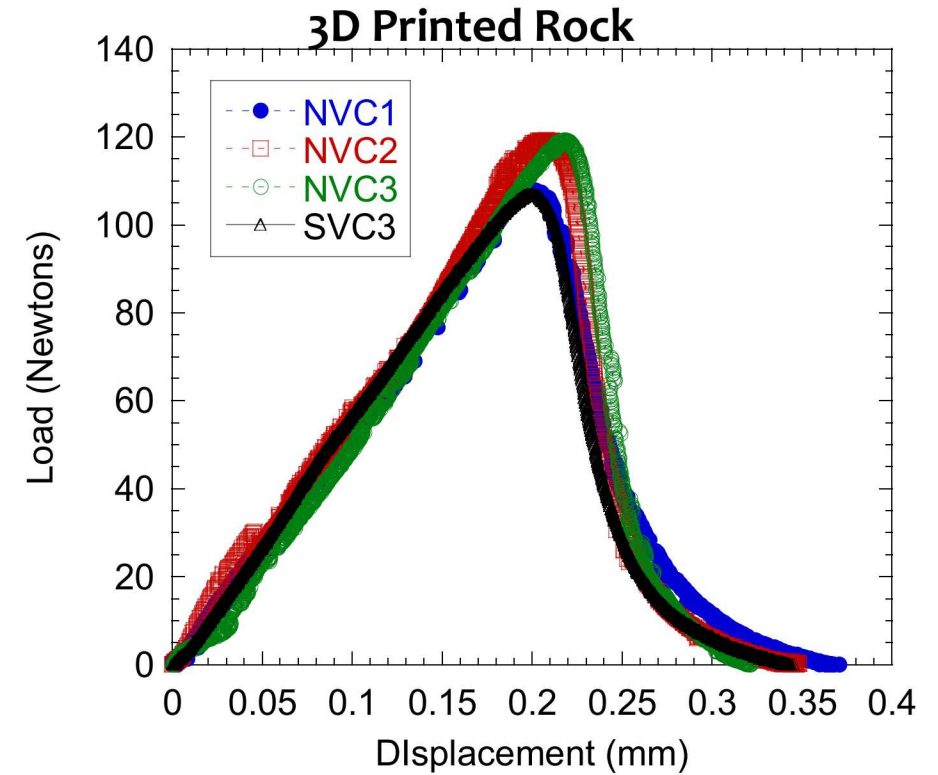
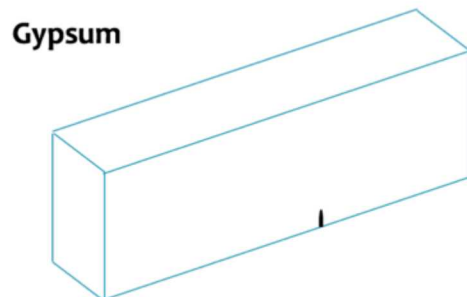
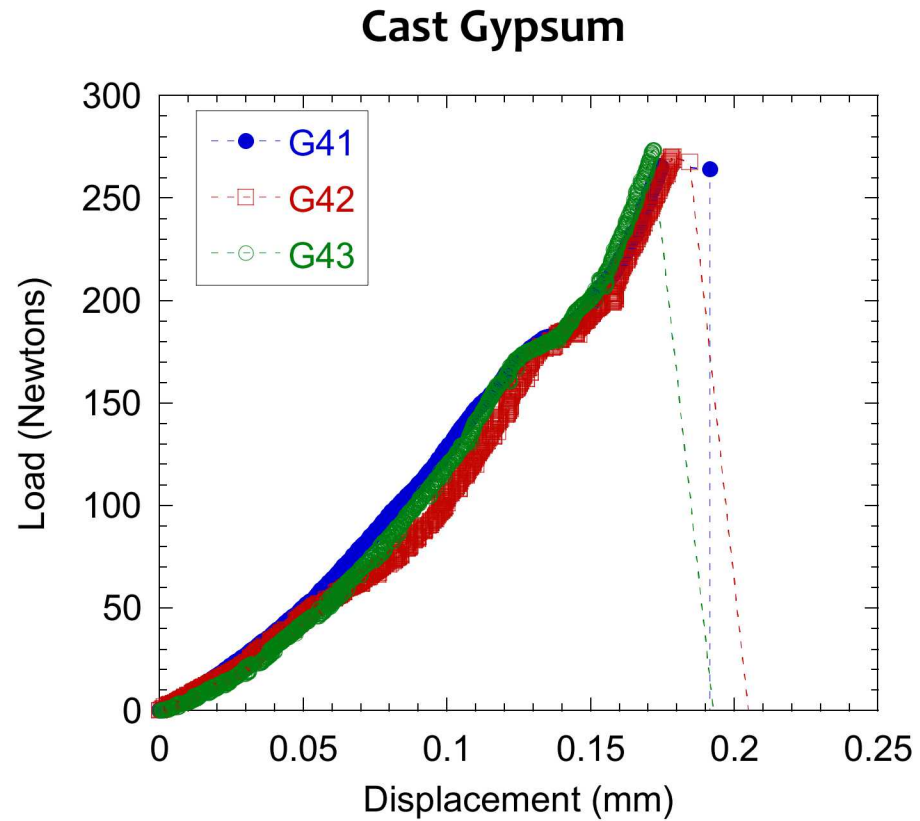


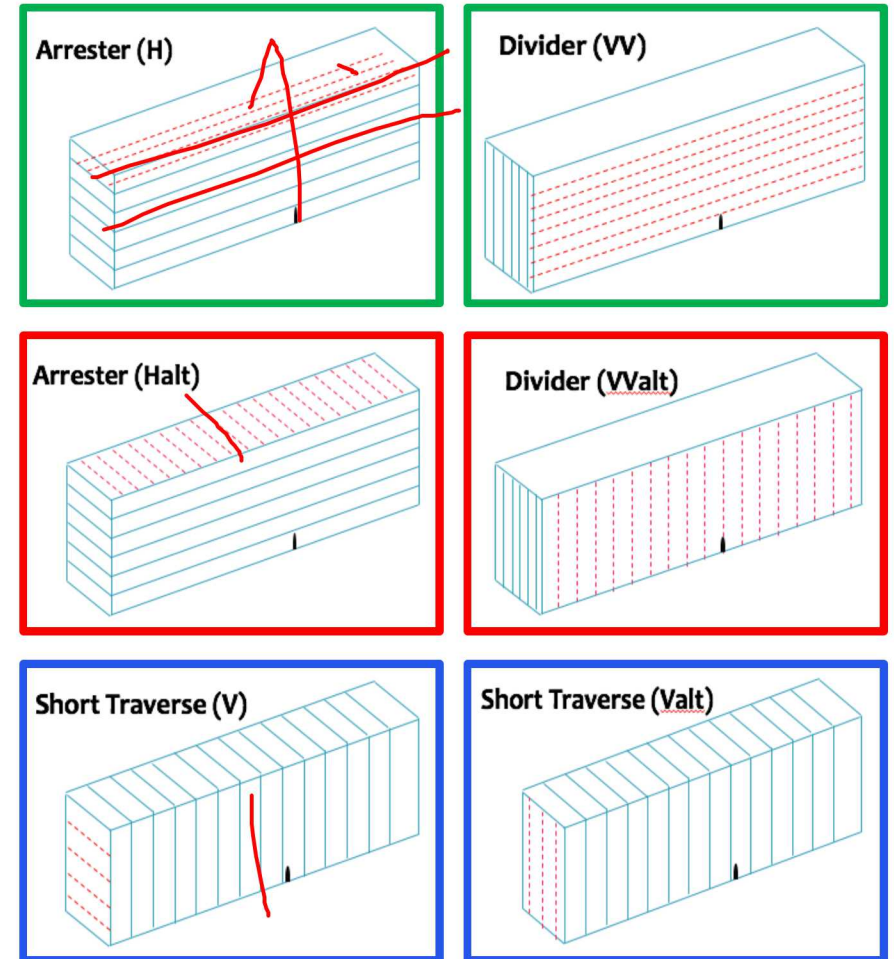
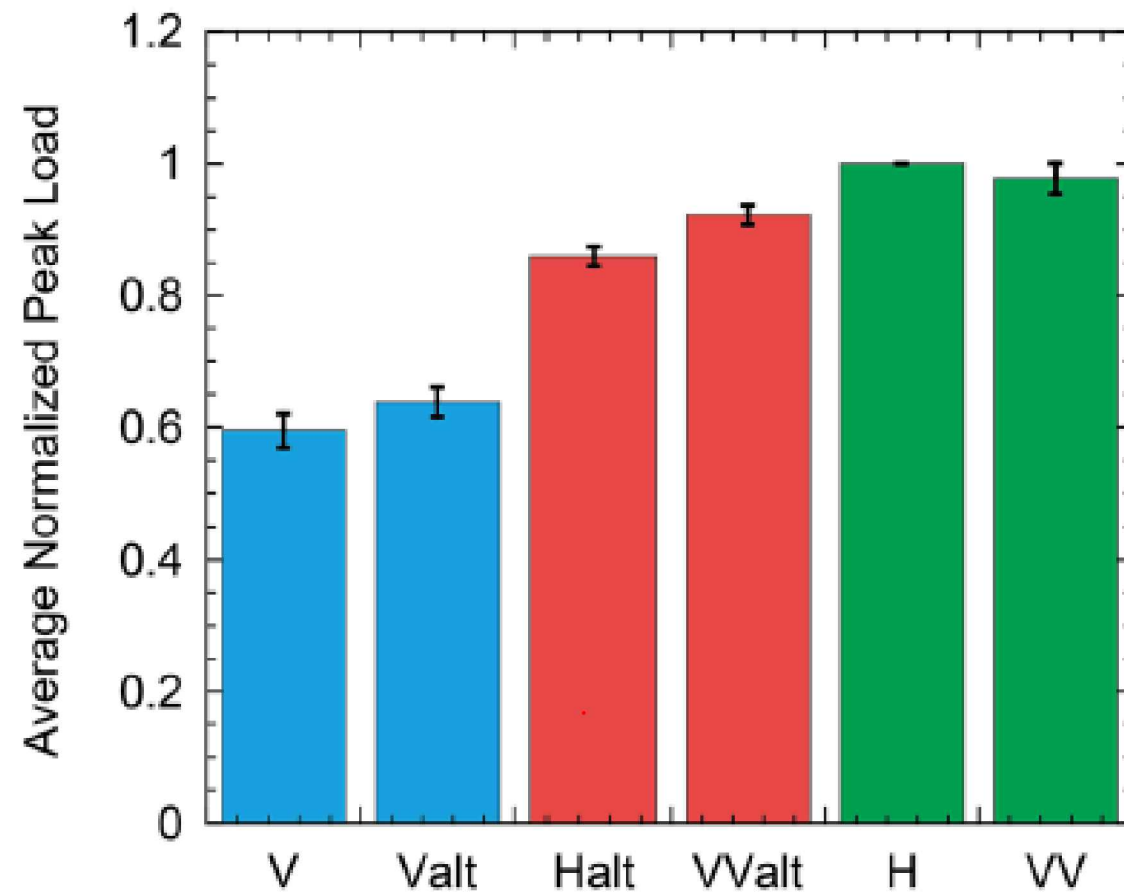
Polarization relative to layering

*With additional measurements elastic constants can be obtained



9 Three Point Bending Experiments: Repeatability

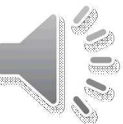
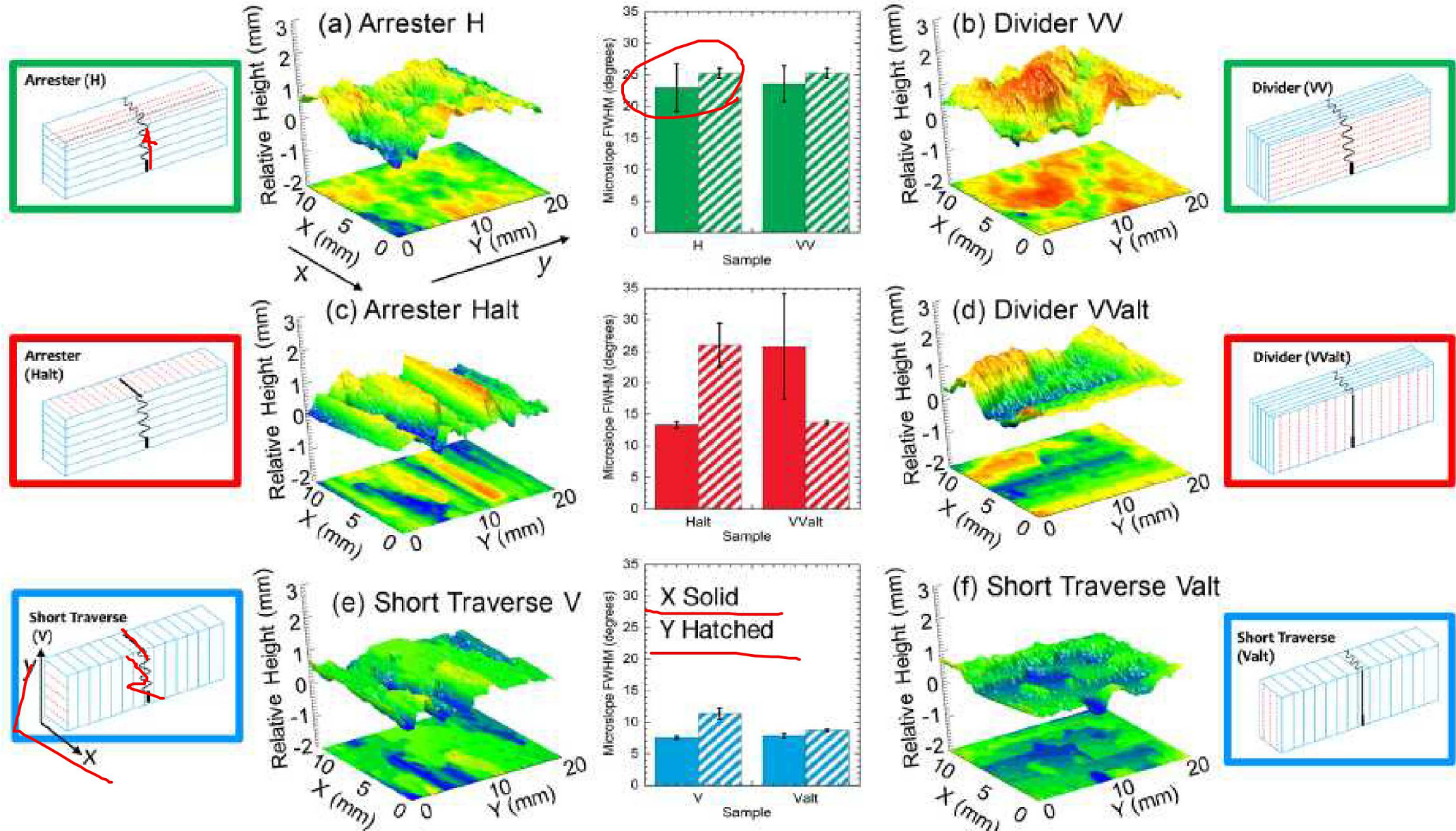




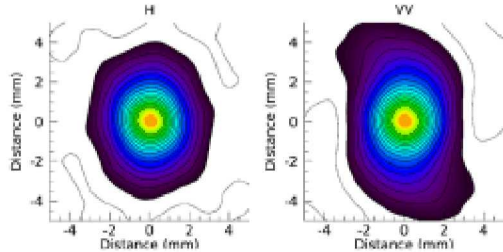
Fracture roughness and mineral texture

Stronger

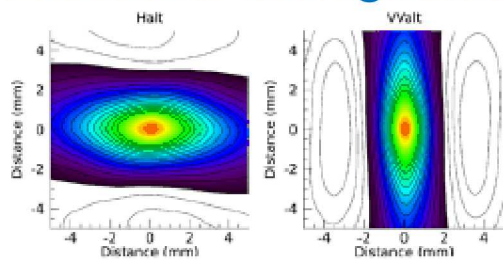
Weaker



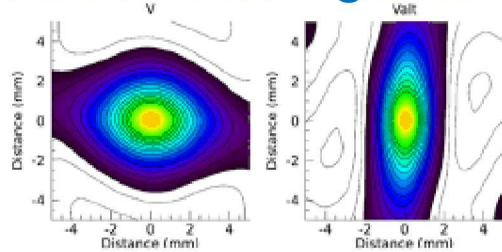
**Strongest isotropic -
Suppresses corrugations**



**Intermediate anisotropic -
Enhances corrugations**

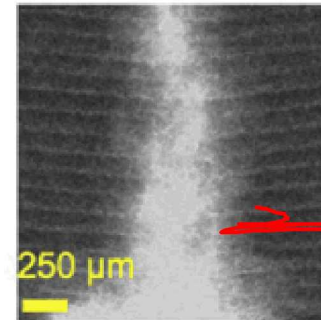
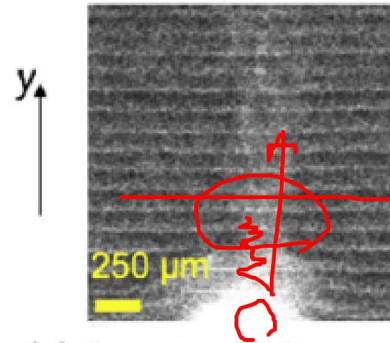


**Weakest anisotropic -
Generates corrugations**



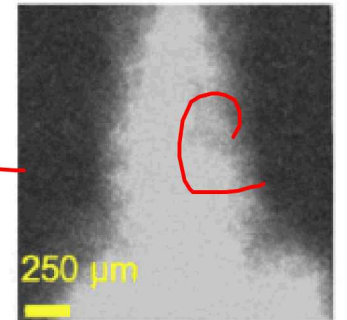
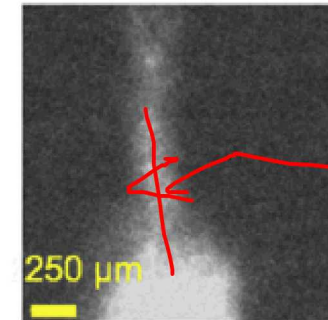
5% of peak load Before failure

(a) Arrestor H

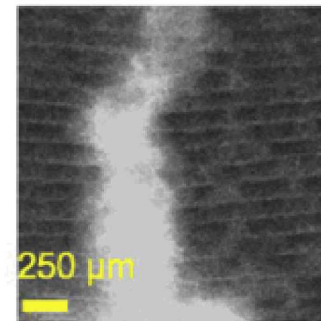
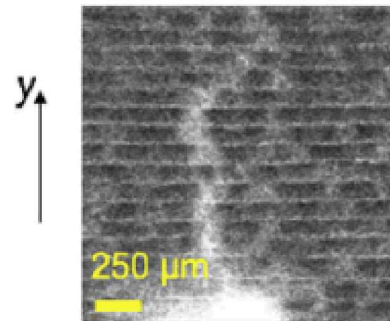


5% of peak load Before failure

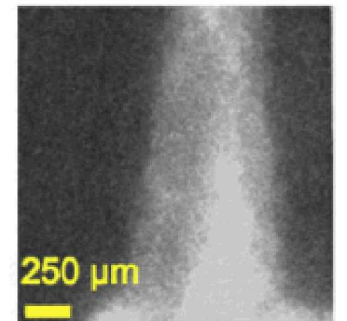
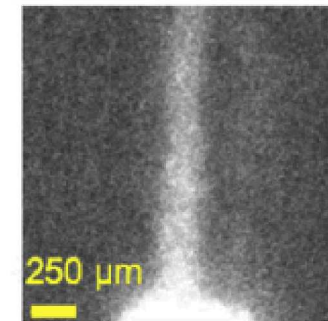
(b) Divider VV



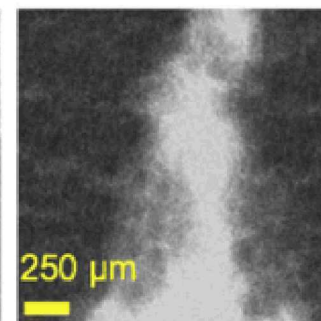
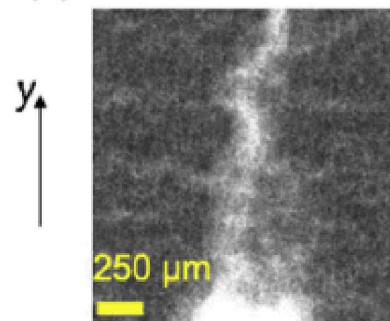
(c) Arrestor Halt



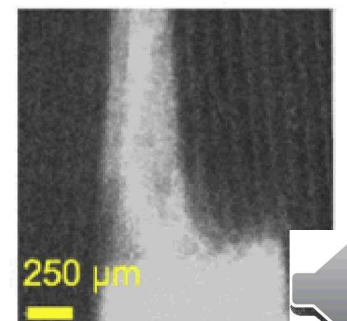
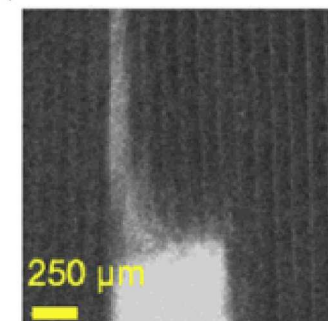
(d) Divider VValt



(e) Short Traverse V



(f) Short Traverse Valt



- ▶ With “geo-architected” rock samples we were able to provide the first demonstration of the role of mineral texture orientation on fracture surface roughness.
- ▶ This unique correspondence between the fracture geometry and the relative orientation of layers and mineral texture in rock opens the door to accurate prediction of fluid flow anisotropy.
- ▶ Integration of multiphysics (geomechanical and geophysical approaches) and multiple tools (controlled experiments, simulations, machine learning) for sensing and data analysis will enable us to advance both fundamental and practical study of a wide range of geoscience applications.

