SAND2017-6716D

iSAFE Interns for Security, Arms control and Force protection Engineering

# Integrated Analysis of Chalk


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Geoscience is a diverse field requiring a variety of skill sets to collaborate in order to better understand the natural and engineered environment. This project aims to model complex flow patterns through rocks, specifically carbonate chalk, by combining image processing, additive manufacturing, and computational fluid dynamics.

## Image Processing and Analysis

We collected data sets of natural rocks using focused ion beam-SEM technique to convert a series of images into 3D models. First, we aligned and filtered the images for registration and pre-processing in sequential images. Next, we used a combination of segmentation techniques to distinguish the solid from the pore space resulting in a set of binary images. From the binary Images, we created a 3D model which can be converted into an STL file for meshing.

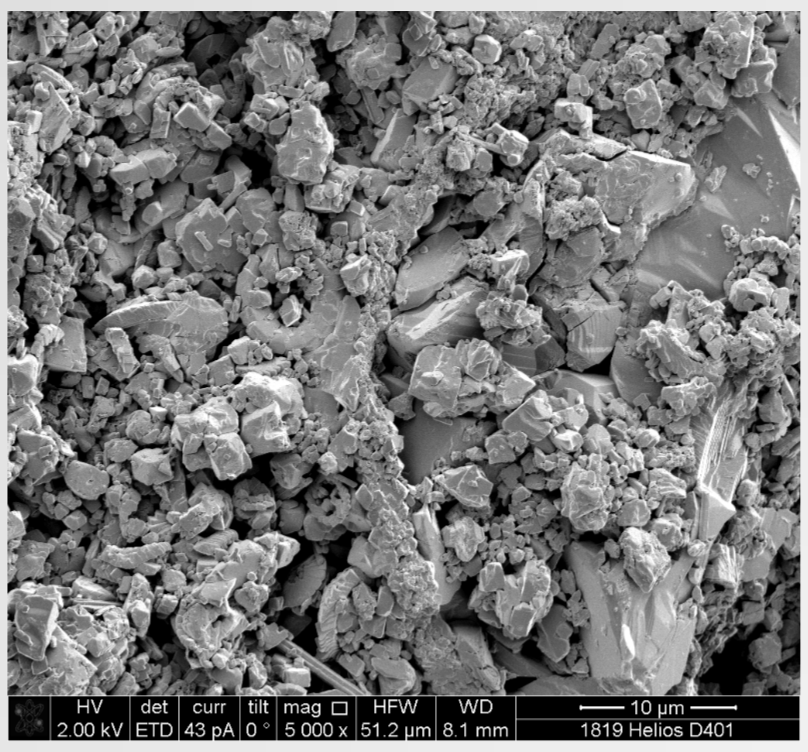

**Figure 1:** SEM image of carbonate chalk. Width of image is ~ 60 microns.

## Segmentation Techniques

We used two segmentation techniques: watershed and p-algorithm. Both algorithms were used because of their ability to capture unique pore sizes.

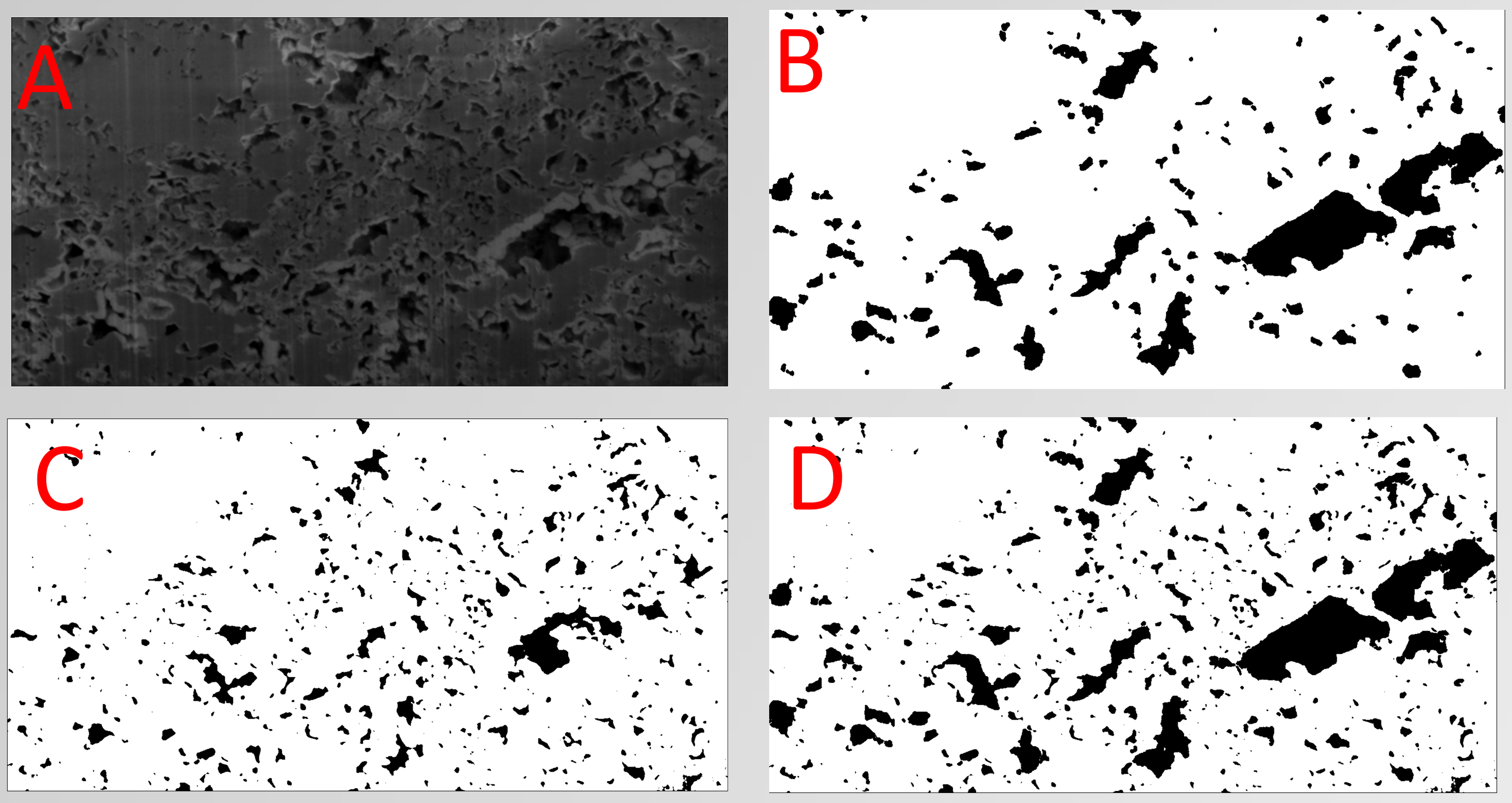


**Figure 2:** A) Original FIB-SEM Image (~2mm width). This wide image at 1 micron resolution was only possible with plasma-FIB, B) Watershed segmentation, C) P-Algorithm segmentation, and D) Combined Results

- Watershed: creates a gradient of color values from 3D images to determine catchment basins. These basins were then manually analyzed to determine depth. This process resulted in a better analysis of larger pore space. However, because of the manual aspect, smaller pores were difficult to capture.
- P-algorithm: is an automated process capable of analyzing small pores. It creates an initial segmentation that is then compared at each hierarchical image to reintroduce the maxima and reduce over segmentation.

## Fluid Simulations

We examined the effects of different contact angles on various obstacles in capillary microfluidic channels. The computational fluid dynamics (CFD) software, OpenFOAM, was used to conduct the simulations. OpenFOAM is a C++ library containing many different solvers capable of analyzing a myriad of situations. The main multiphase solver used in the analysis was interFoam. This solver analyzes both gaseous and liquid phases using volume of fluid algorithm in space and time.

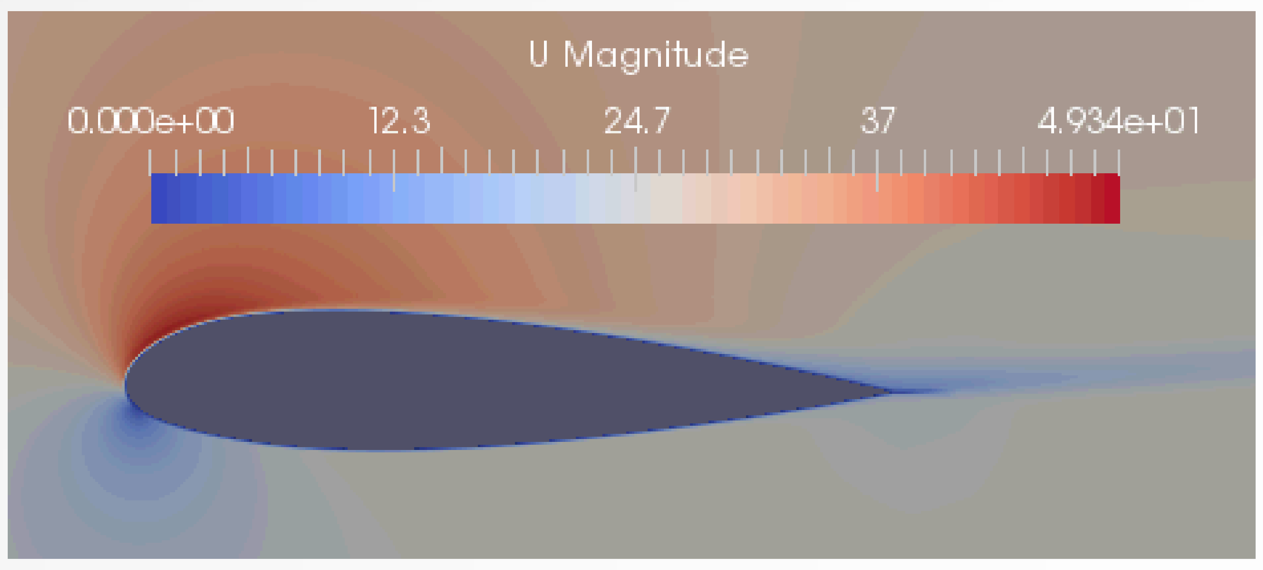


**Figure 3:** 2D Airfoil Simulation of Velocity Field


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U.S. DEPARTMENT OF ENERGY

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## Additive Manufacturing and Experiments

The experimental samples were designed and 3D printed for validating the CFD simulations. Two 3D printing techniques were considered: Stereolithography (SLA) and Fused Deposition Modeling (FDM). SLA was selected because of finer resolution and superior optical properties. The contact angle, or wettability, of the printed material is measured using the Sessile Drop Technique.

https://www.cnet.com/videos/the-formlabs-form-2-is-more-than-an-expensive-3d-printer

**Figure 4:** SLA printer

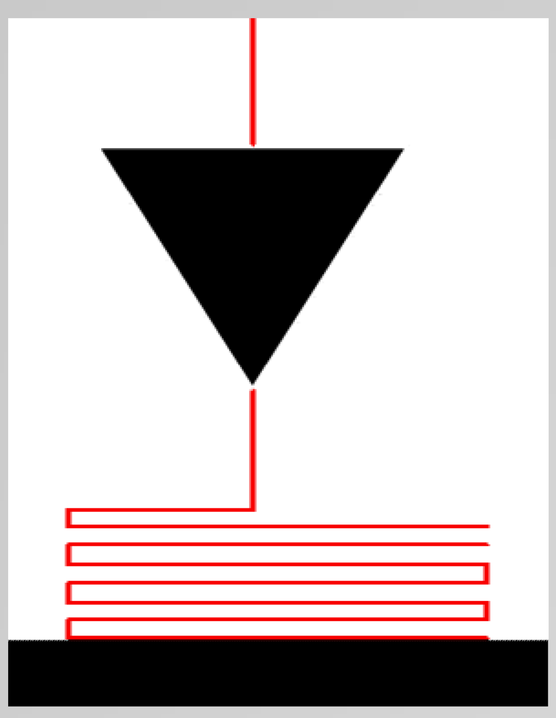

**Figure 5:** FDM printer

## Experimental Fluid Dynamics

The 3D printed samples are tested by injecting fluid through a syringe. Pressure transducers and thermocouples are used to record pressure and temperature at various points in the sample. A microscope is used to capture detailed images of the flow patterns, and measure the contact angle on the obstacles.

## Multiphase Fluid Behaviors

The dominating force in microfluidics is capillary action. A capillary number of less than $10^{-5}$ indicates that the flow is driven by capillary forces. High surface tension and low velocities cause this phenomena. This is commonly found in porous media, such as chalk.

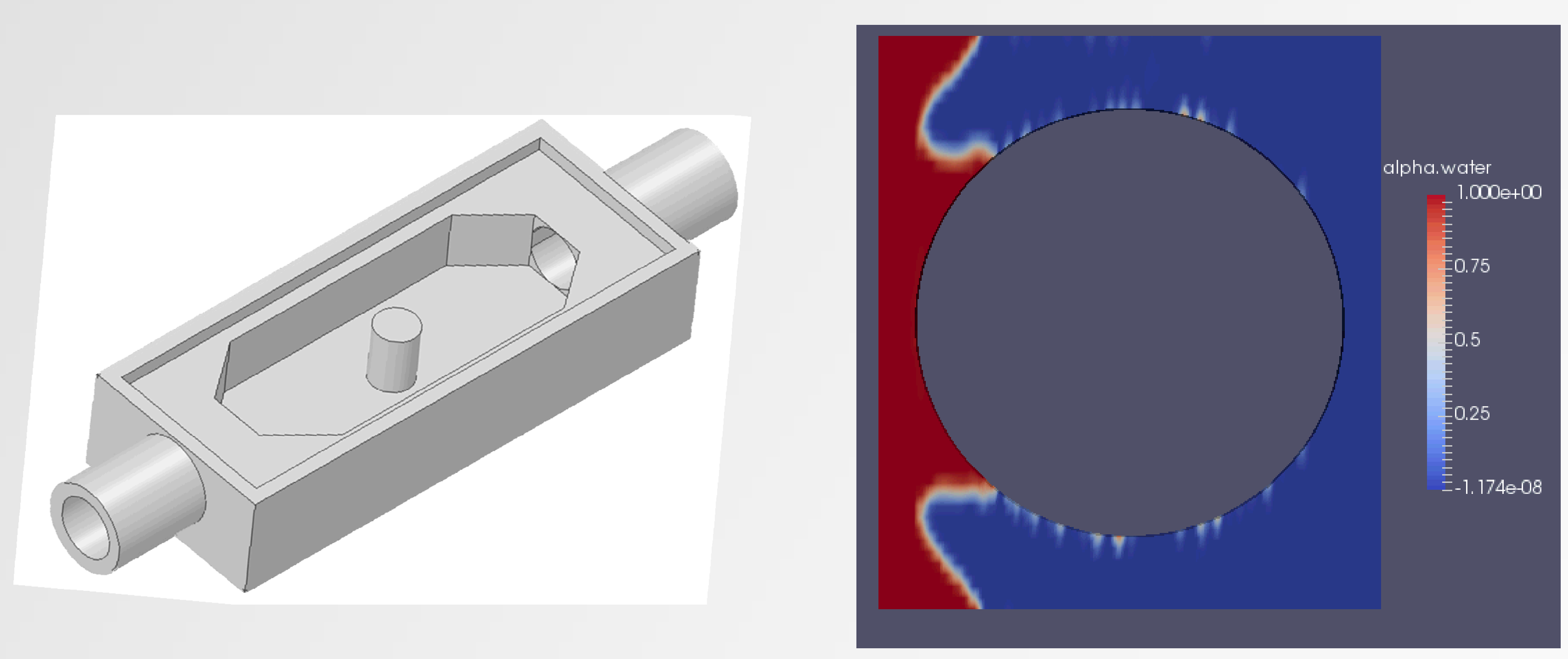


**Figure 6:** Comparison of CAD model (left) to OpenFOAM simulation (right)

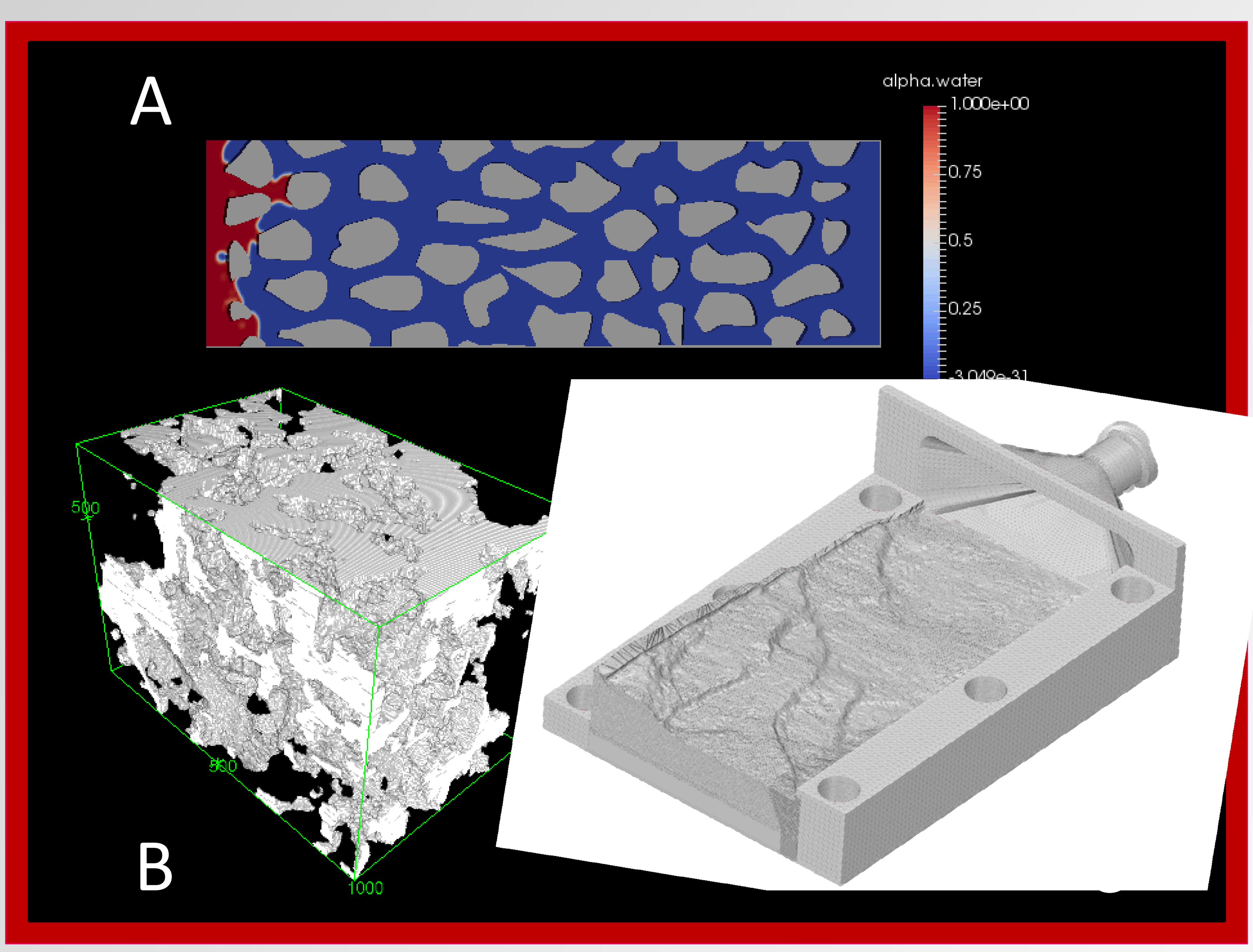


**Figure 7:** A) CFD Simulation in 2D porous media, B) 3D binary model of carbonate chalk, and C) 3D CAD model of fracture in shale (only half of the domain shown)

## Future Work

The ability to model and test multiphase flow in porous media samples is a promising development for geoscience applications. Going forward, more testing is required to validate the CFD simulations and image processing techniques. This will result in an increased understanding of mechanical and fluid properties of these types of materials for energy security applications.

### Acknowledgments

This work was supported by the Laboratory Directed Research and Development program at Sandia National Laboratories and also partly supported from the U.S. Department of Energy, the Office of Science, Basic Energy Sciences under Award Number DE-SC0006883.