A Visual Journey into the Unexplored Realm of Rocks: Pore Network Investigation in Marcellus Shale Rock Matrix**

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Abstract

The ever-growing energy demand and recent discoveries of vast unconventional oil and gas reservoirs have brought significant attention to shale oil and gas resources as potential game-changers for the petroleum industry and energy markets worldwide. The complex structural features and mineralogy of shale has broad implications on the development of the unconventional oil and gas industry. Although shale reservoirs are large in scale and offer the potential for long-lived production, extremely low matrix porosity and permeability, as well as complex heterogeneity, pose major challenges in obtaining economically viable oil or gas. A lack of predictive understanding of microstructure-based heterogeneity in shale limits the effectiveness of currently used production technologies. Hence, addressing the challenges of shale oil and gas production requires an in-depth understanding of microstructural features that control the oil and gas storage, release, and transport mechanisms.

Because anisotropy of shale exists across multiple scales, determining changes in pore distribution has proven to be difficult. Recent studies have indicated that shale pores significantly vary in number, size (from nano- to micro-pores), and classification (organic and nonorganic). Thus far, the role of pore network and, more specifically, what pores contribute the most to the gas and/or oil storage or to the production process, is not well understood and remains largely unknown. Hence, it is vital to determine how well different pores are connected and how they create possible flow pathways for hydrocarbon migration.

Here we present a comprehensive digital rock physics (DRP) framework for pore network investigation in a Marcellus Shale rock matrix. Pore networks within both organic and nonorganic matter are reconstructed from focused ion beam scanning

electron microscopy (FIB-SEM) images of the shale specimen. Through this process, the pore size distribution, porosity, pore connectivity, and mineralogy – organic-matter-hosted and nonorganic-matter-hosted pores – of the sample are obtained. The impact of obtained parameters on fluid flow in shale is analyzed.

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Acknowledgements

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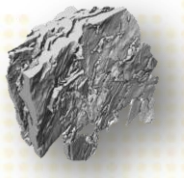
Outline

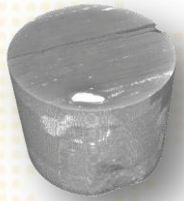
1) Correlative X-Ray and Electron Microscopy
- Nano X-Ray Microscopy (nano-XRM)
- Focused Ion Beam Scanning Electron Microscopy (FIB-SEM)

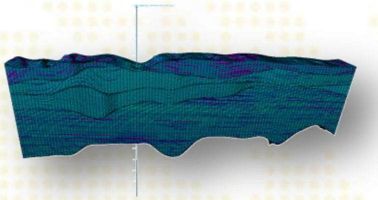
2) Digital Rock Physics (DRP) and Pore Network Modeling (PNM) of Organic- and Nonorganic-Matter-Hosted Reservoir Pore Systems

From Pore to Core and Beyond

RESERVOIR QUALITY







PORE-SCALE CORE-SCALE RESERVOIR-SCALE

Multi-Scale Characterization of Heterogeneous Petroleum Geomaterials/Geosystems

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THERMO HYDRO MECHANICAL CHEMICAL

Experimental and Numerical Analysis of Coupled THMC Processes

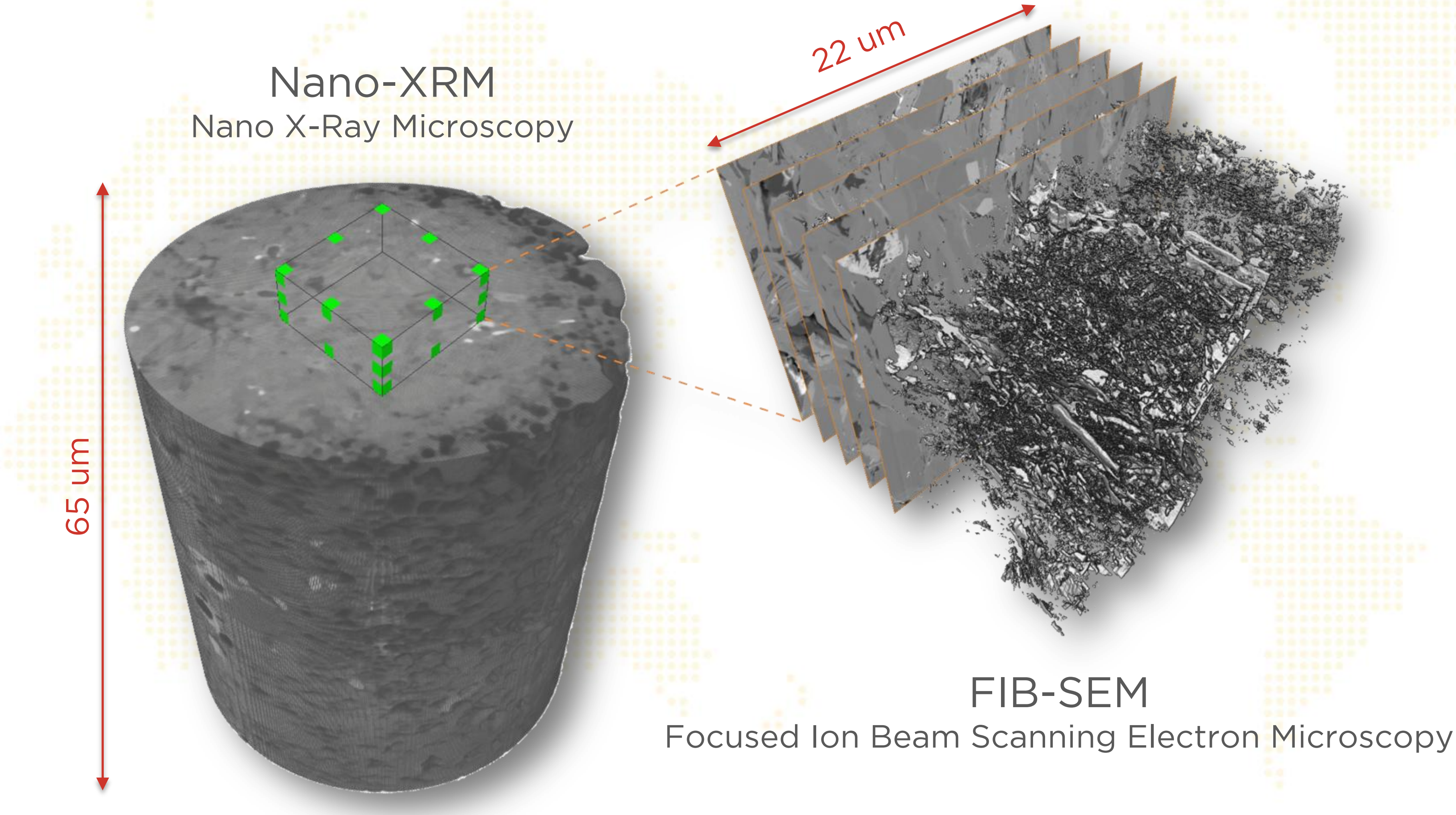
↓

COMPLETION QUALITY

Objectives

- Identify, Separate and Quantify Organic and Nonorganic (Mineral) Matter within Marcellus Shale Rock Matrix
- Identify, Separate, and Quantify Total and Connected (Effective) Pore Networks within Marcellus Shale Rock Matrix
- Identify Pore Types within Marcellus Shale Rock Matrix
- Identify, Separate, and Quantify Total and Connected (Effective) Organic- and Nonorganic-Matter-Hosted Pore Networks within Marcellus Shale Rock Matrix

Correlative X-Ray and Electron Microscopy



Correlative X-Ray and Electron Microscopy

Nano-XRM

Dimensions: ⌀ 65 x 65 um

Voxel size: 65 nm

Data set: 901 radiographs

FIB-SEM

Dimensions: 22 x 22 x 10 um

Voxel size: 10 nm

Data set: 1,982 images

Digital Rock Physics (DRP) and Pore Network Modeling (PNM)

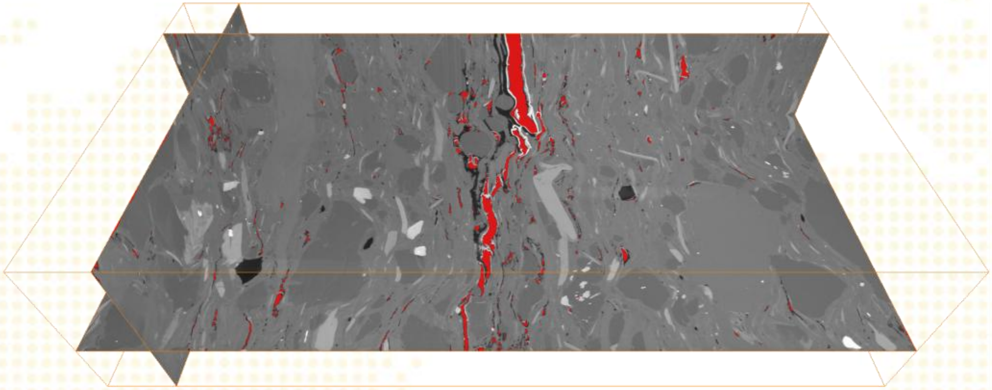
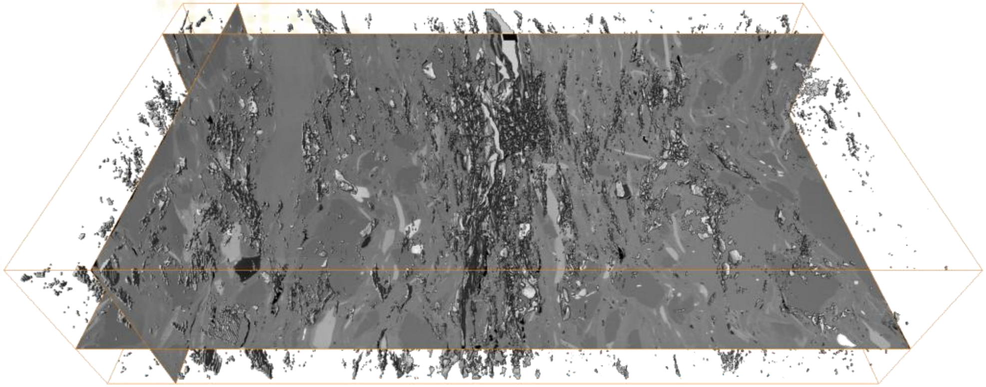
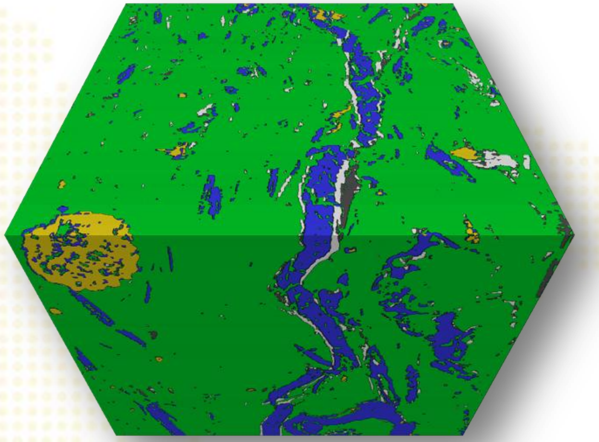


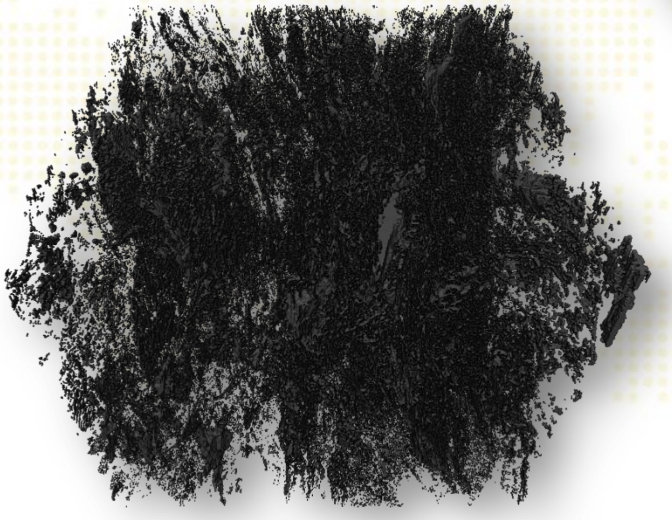
Image Processing and Segmentation



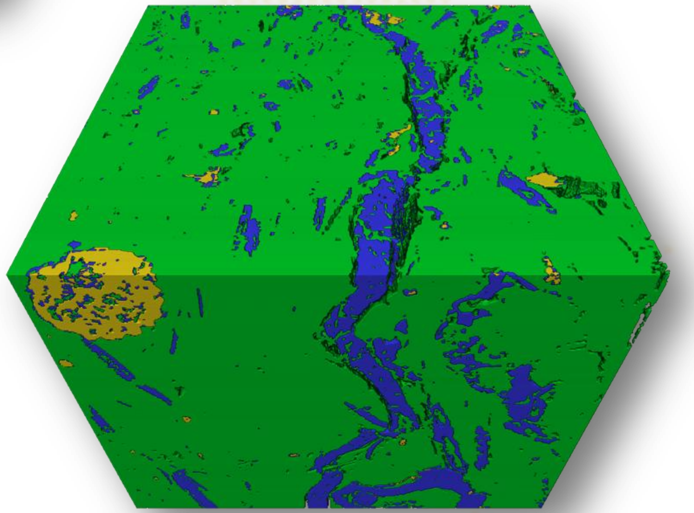
Model Reconstruction and Visualization

Organic vs. Nonorganic Matter



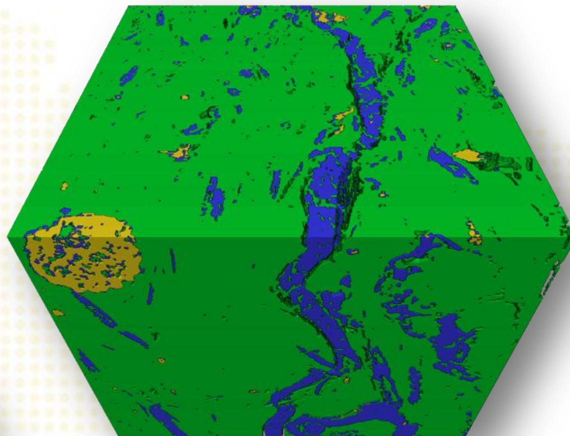


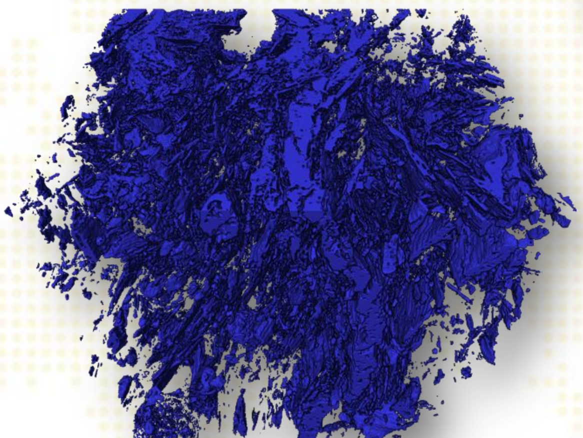
Organic Matter 2.32%



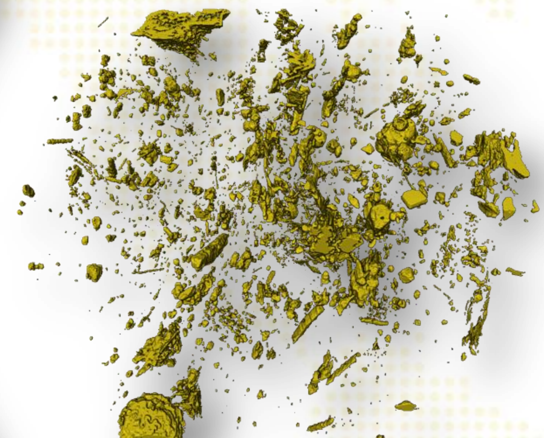
Nonorganic Matter 95.24%

Nonorganic (Mineral) Matter



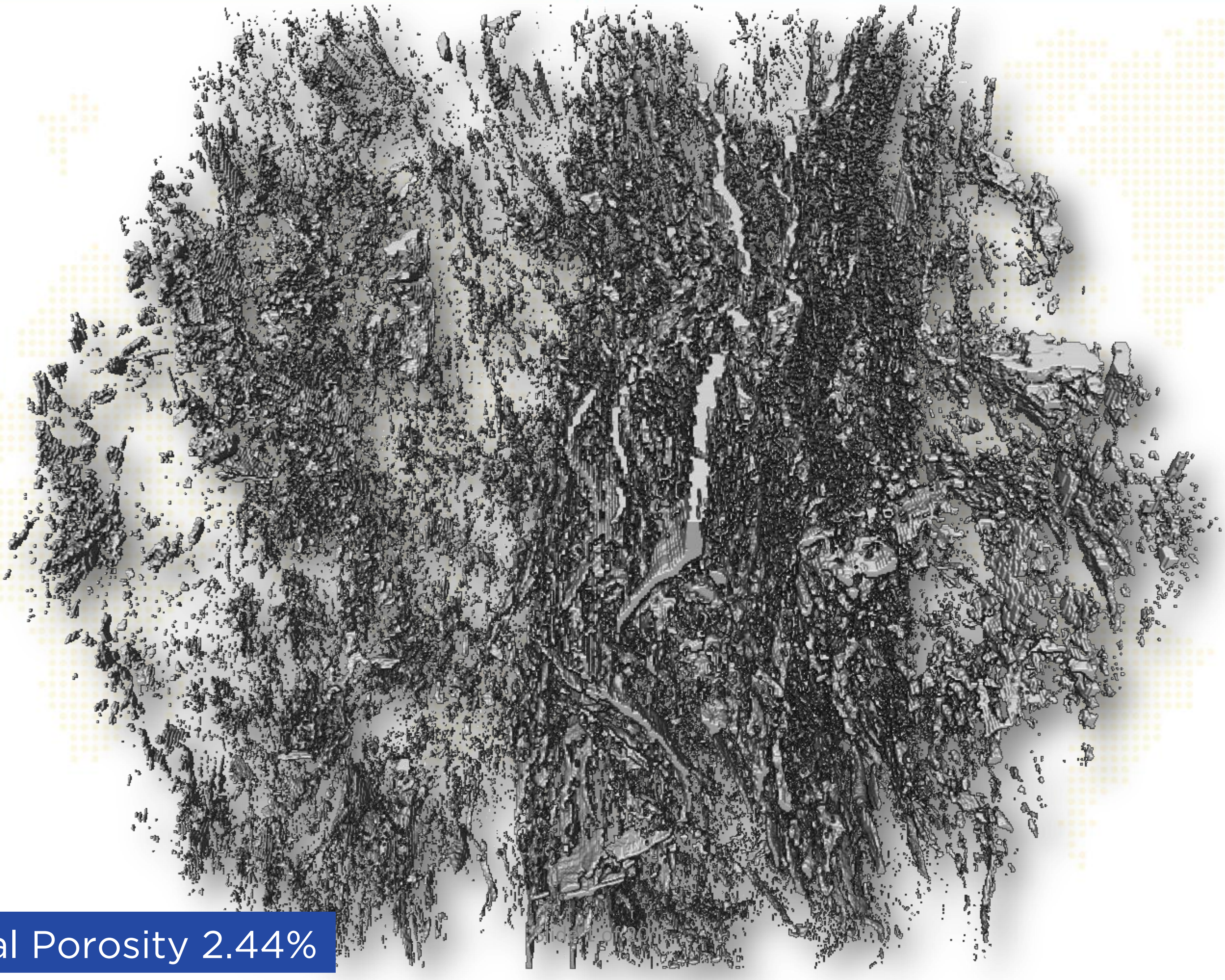


Carbonate 10.96%

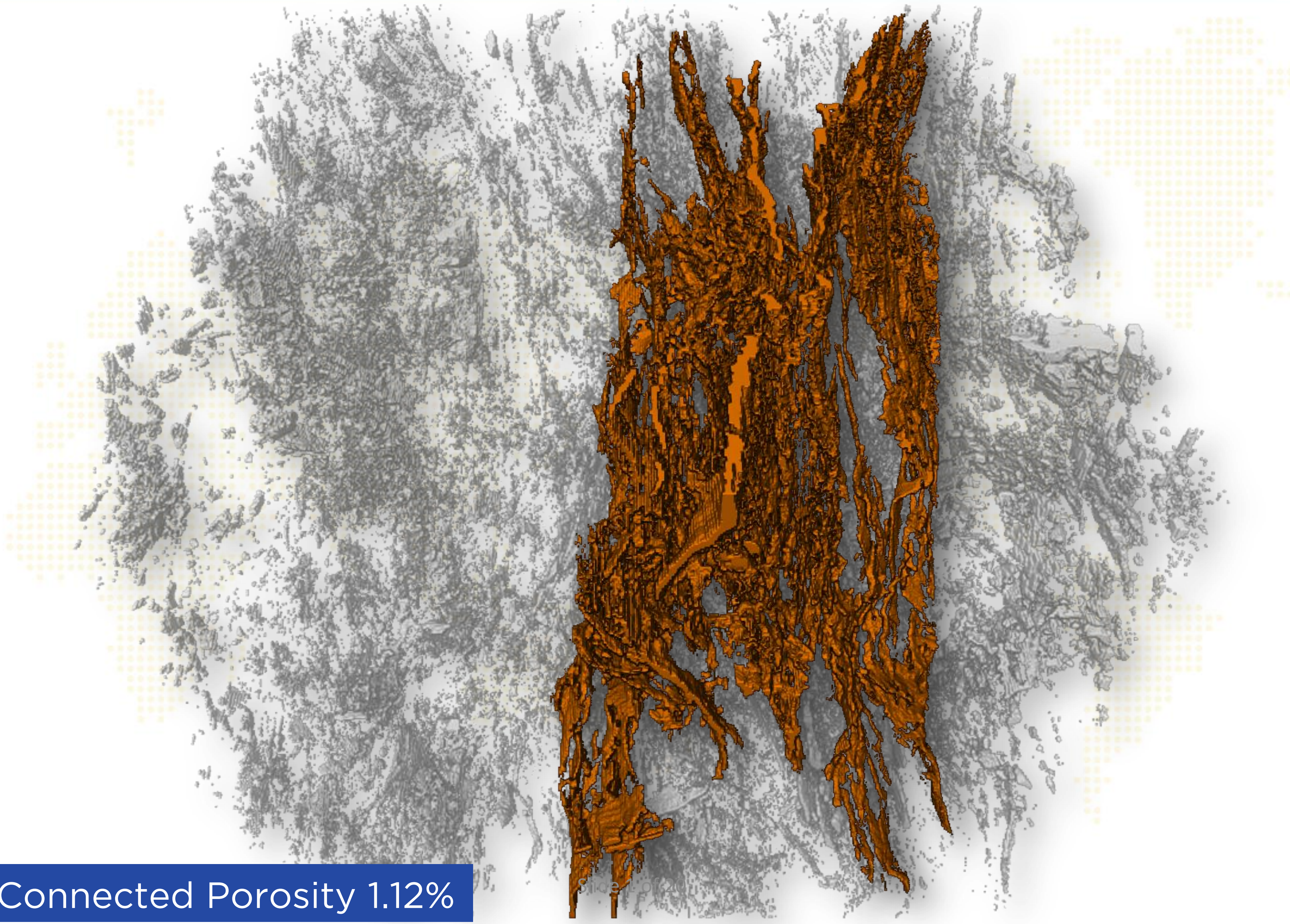


Sulfide 1.22%

Silicate 83.06%

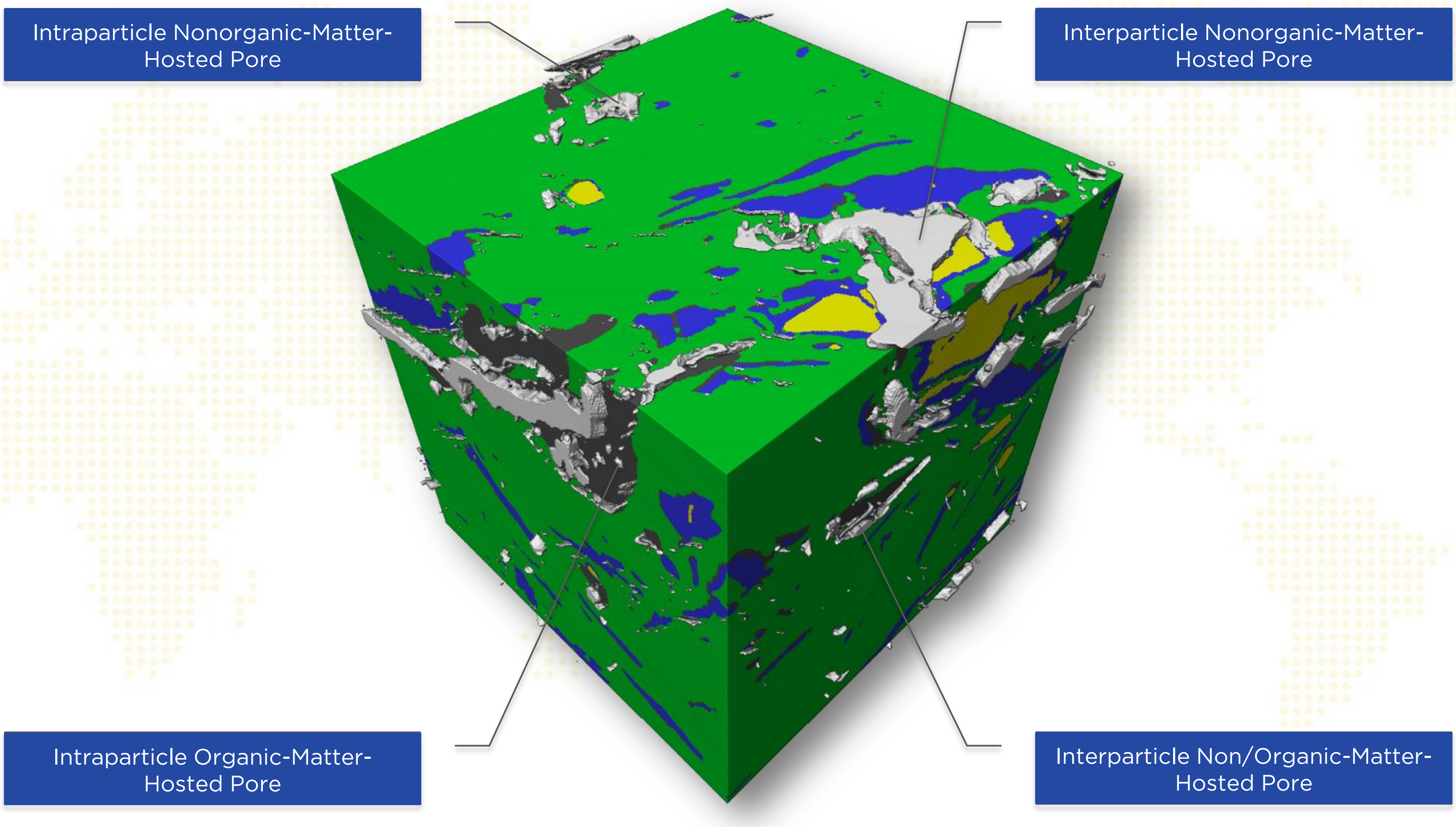


Total Porosity 2.44%

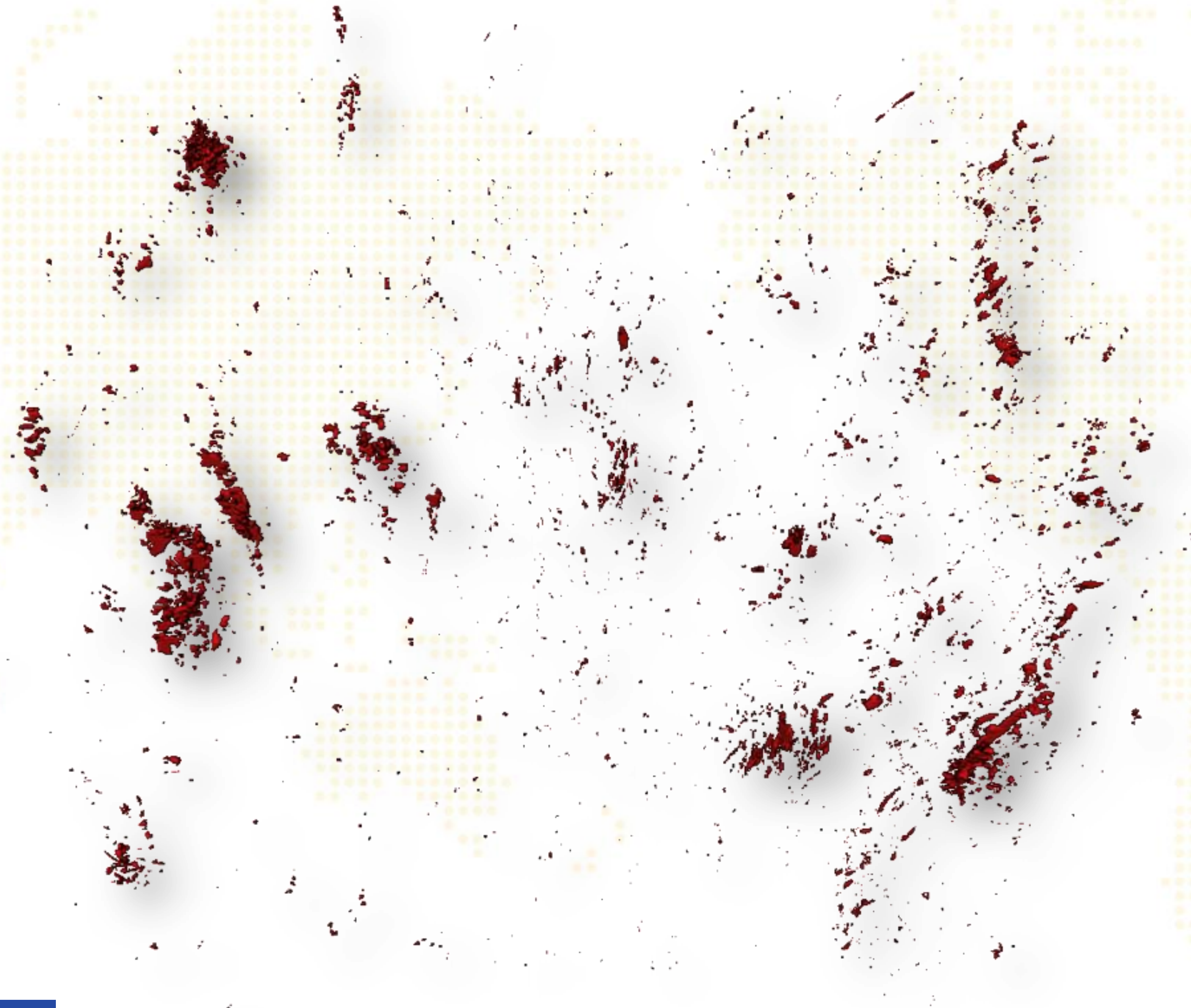


Connected Porosity 1.12%

Pore Types within 5 um^3 Shale Rock Matrix

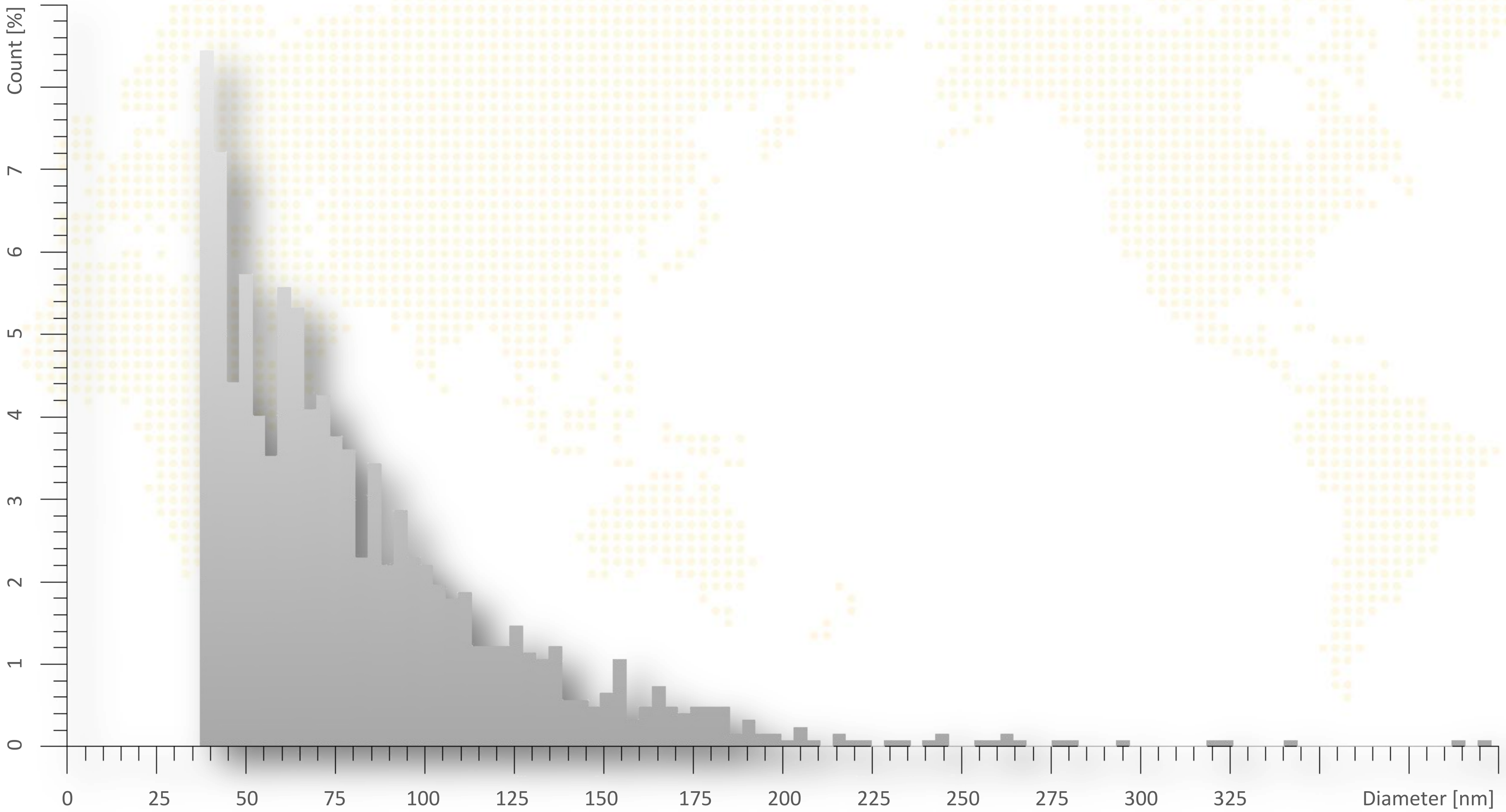


(Intraparticle) Organic-Matter-Hosted Pore Network

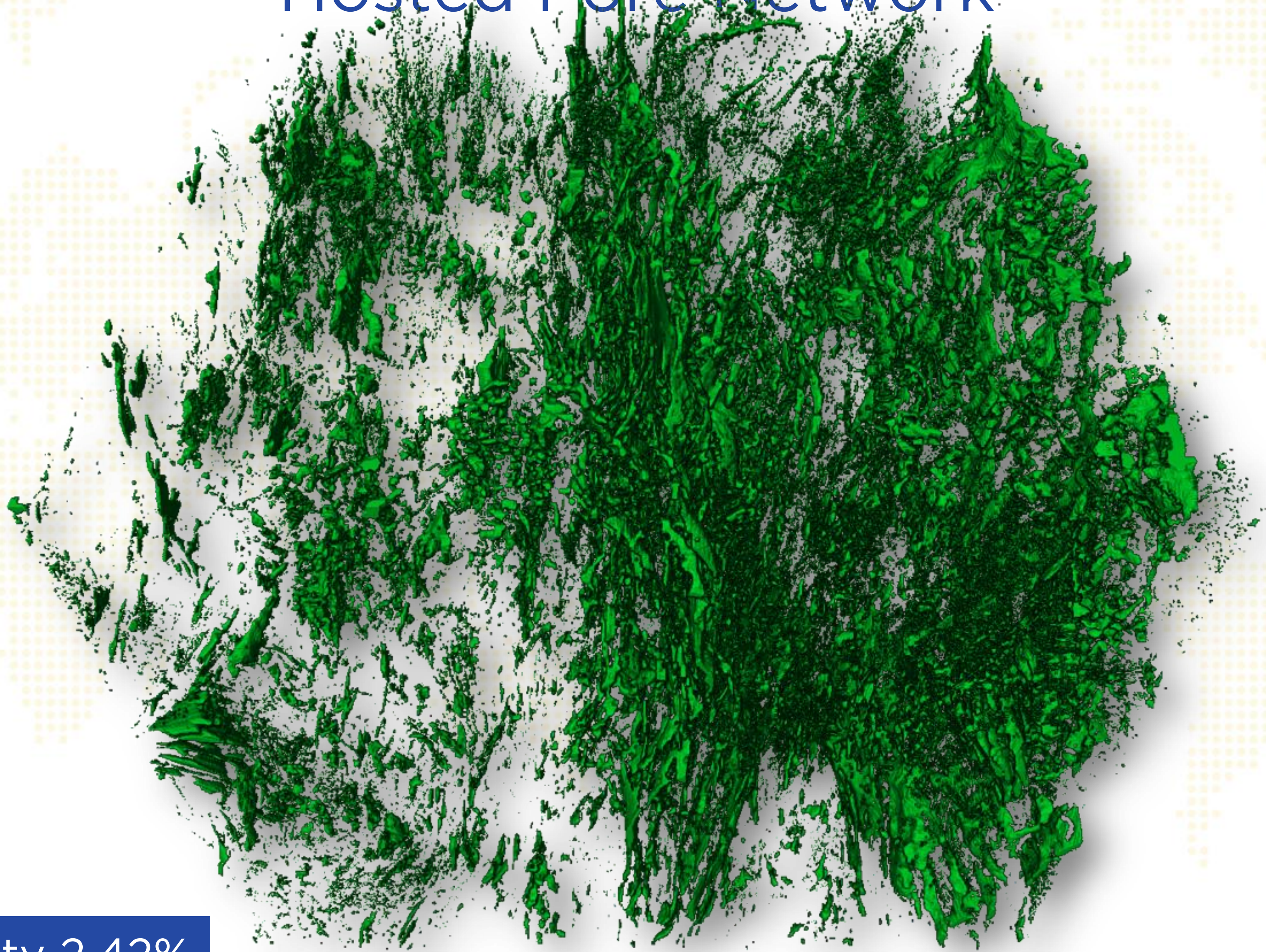


Porosity 0.02%

Pore Size Distribution (PSD) of Organic-Matter-Hosted Pore Network

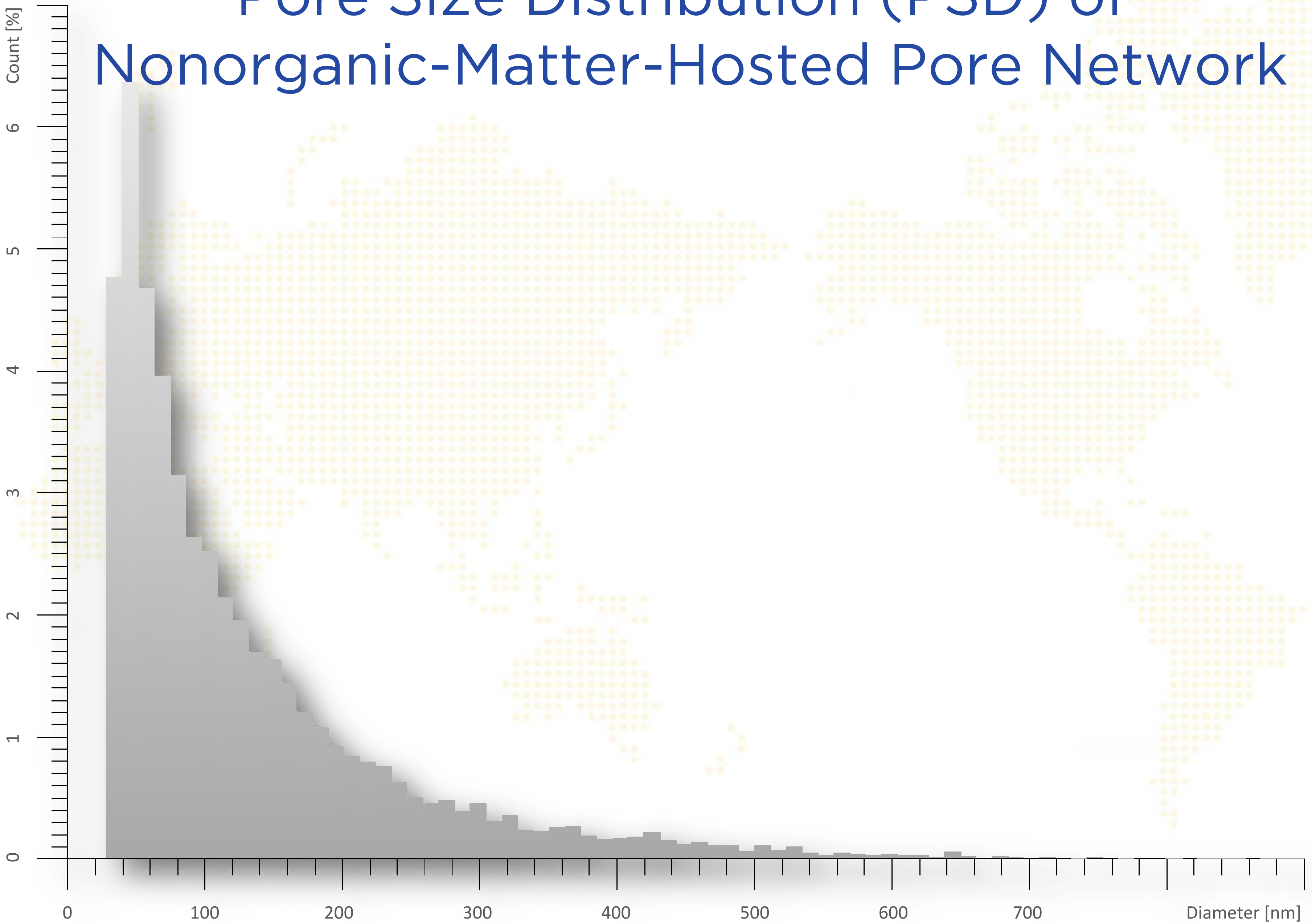


(Intra- and Interparticle) Nonorganic-Matter-Hosted Pore Network



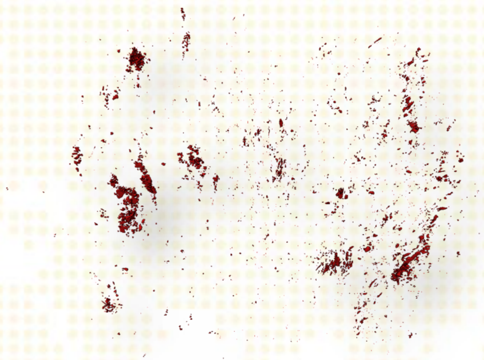
Porosity 2.42%

Pore Size Distribution (PSD) of Nonorganic-Matter-Hosted Pore Network



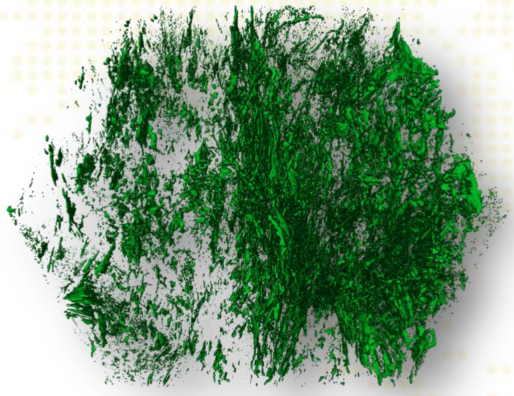
Organic- vs. Nonorganic-Matter-Hosted Reservoir Pore System

Organic-Matter-Hosted Pore Network



0% Connected Porosity

Nonorganic-Matter-Hosted Pore Network



0.93% Connected Porosity

Conclusions

- The Marcellus Shale rock matrix was found to contain both intraparticle organic-matter-hosted pores, and intra- and interparticle nonorganic-matter hosted pores.
- Nonorganic-matter-hosted pores, having the potential for better connectivity, were found to contribute more to the effective pore network, whereas organic-matter-hosted pores were found to only support the overall pore system.

Thank You
Q&A

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