Characterize Millimeter-Scale Unconventional Rock Using Micron-Scale Sample Imaging and Machine Learning*

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Abstract

A thorough knowledge about rock properties is crucial for economic oil and gas exploration. Unconventional resources are known to exhibit multi-scale and highly heterogeneous pore structure. Imaging techniques are widely used to visualize and study rock properties. Due to limitations in imaging technology, less than 1% of a rock sample area can be sampled and studied at high resolution. Obviously, relevancy and representativeness of sampling area as well as obtained rock properties are often considered unreliable. We present an in-house developed technology that combines imaging techniques with machine learning to characterize multi-scale rock properties. The technology is based on the understanding that a rock consists of building blocks, i.e. fabrics, intermixed spatially at various scales. Detailed knowledge of all fabrics at its representative scale will lead to an improved characterization of the rock sample. A fabric possesses a set of properties, e.g. porosity, fraction of organic matter, pore size distribution and others. Unsupervised machine learning is used to learn about fabrics present in a sample. It also recommends optimum sub-sampling areas for smaller-scale higher resolution image acquisition and properties upscaling. The required resources in this approach are several orders of magnitude lower than acquiring mosaics of small-scale images covering a similar area at the large scale.

We apply the present technology to acquire images and characterize pore properties of rock samples from the Eagle Ford, Marcellus, and Bakken units. The rock sample area is approximately 0.5×0.5 [mm] with a resolution of 244 [nm]. Small-scale images with an area of approximately 30×18 [micron] with a resolution of 10 [nm] are used to characterize pores within fabrics. The upscaled pore properties and fractions of organic matter are compared with that derived from small-scale mosaic covering a similar area. The comparison shows a very good agreement confirming the accuracy and reliability of the present technology. The present work demonstrates a novel approach to characterize multi-scale rock properties using machine learning technique. This is a step towards bridging knowledge from pore scale (where hydrocarbon lives) to the reservoir scale (where production takes place) for economic oil and gas exploration.

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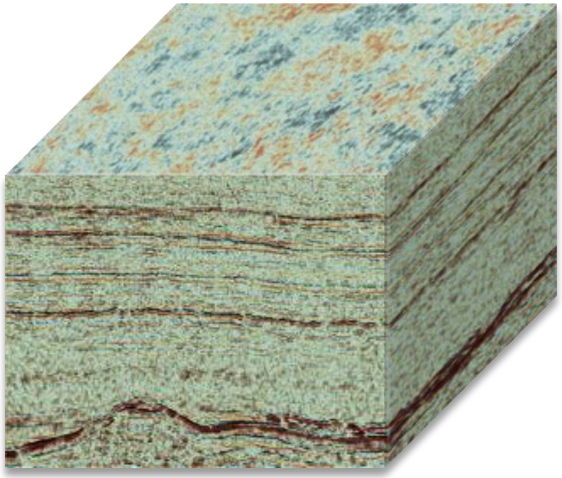
Unconventional Resources – Unconventional Information



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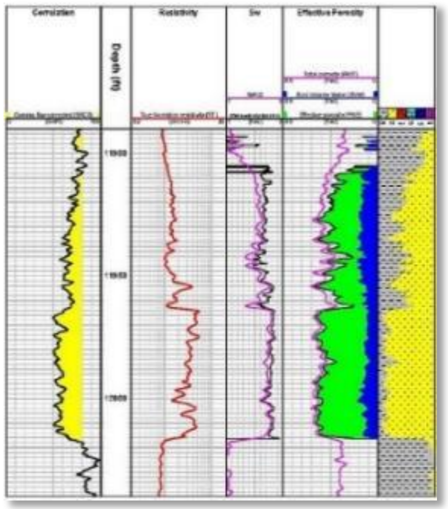

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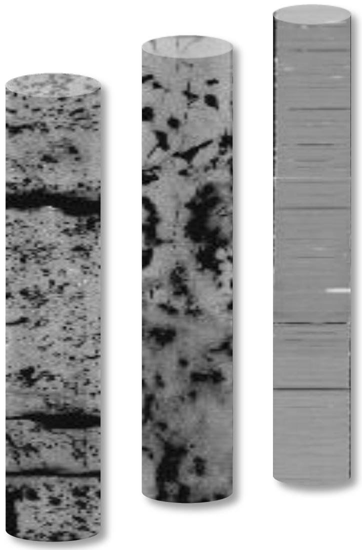

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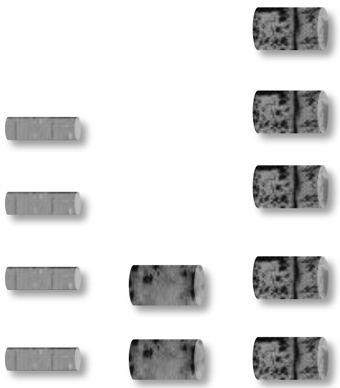

Plugs

Cuttings

kilometers

micron

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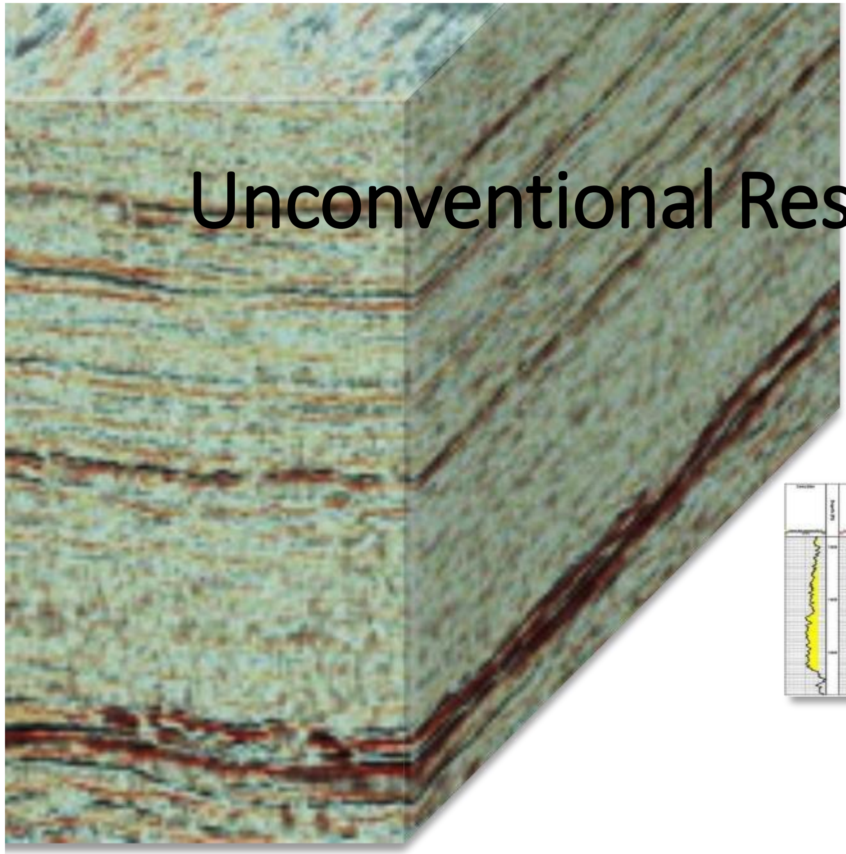
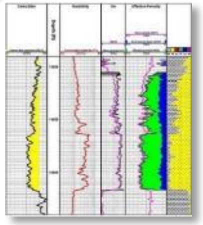
Unconventional Resources – Unconventional Information





Seismic | Well logging | Well cores | Plugs | Cuttings

kilometers → micron

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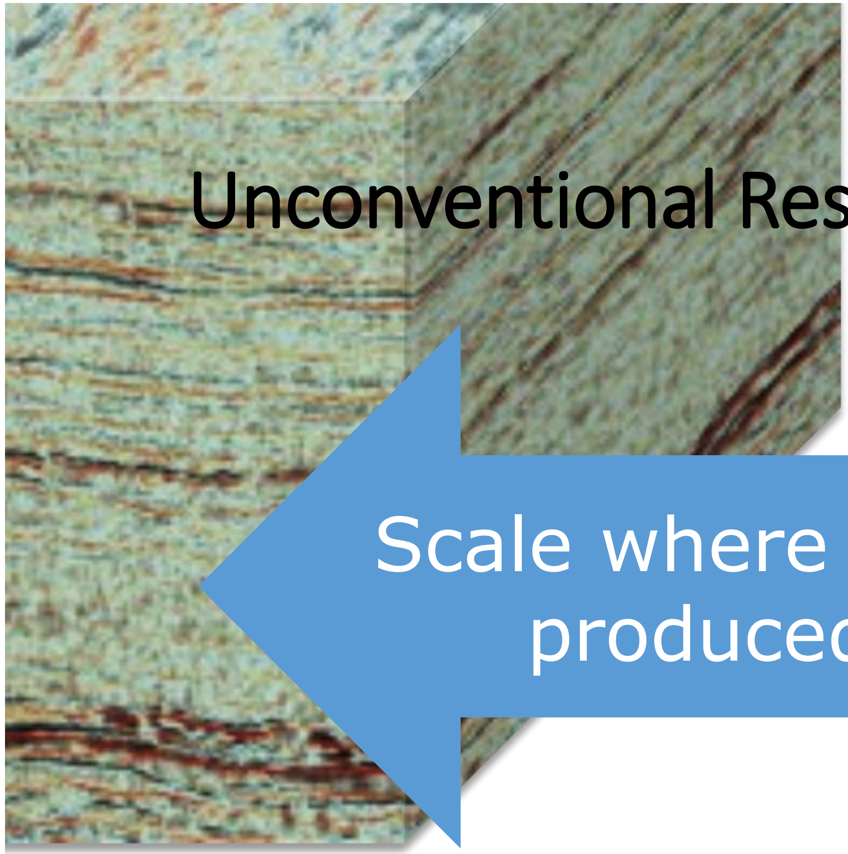
Unconventional Resources – Unconventional Information



Scale where oil is produced

Scale where oil lives

Seismic

Well logging

Well cores

Plugs

Cuttings

kilometers

micron

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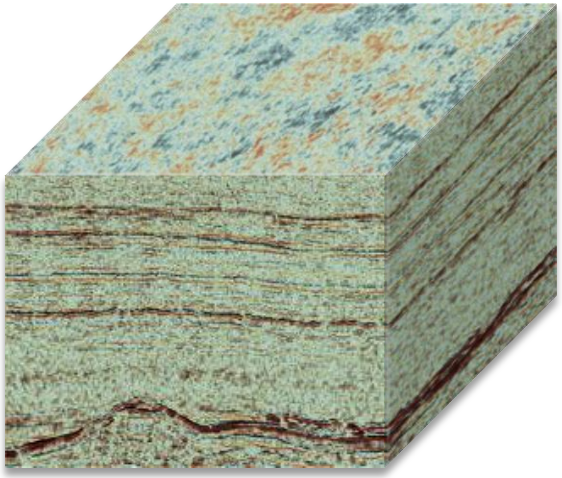
Unconventional Resources – Unconventional Information



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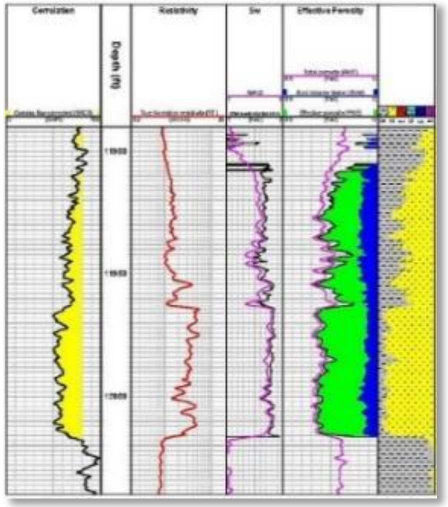

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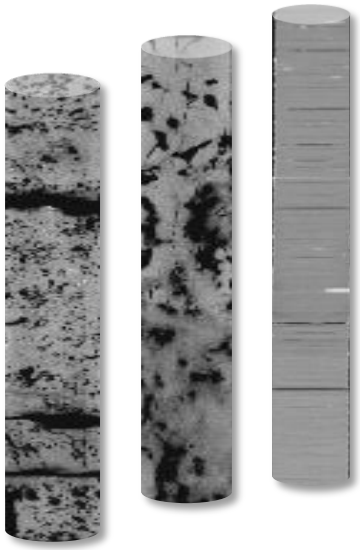

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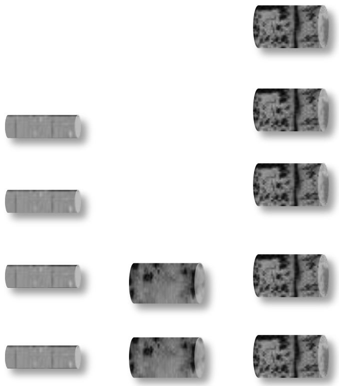


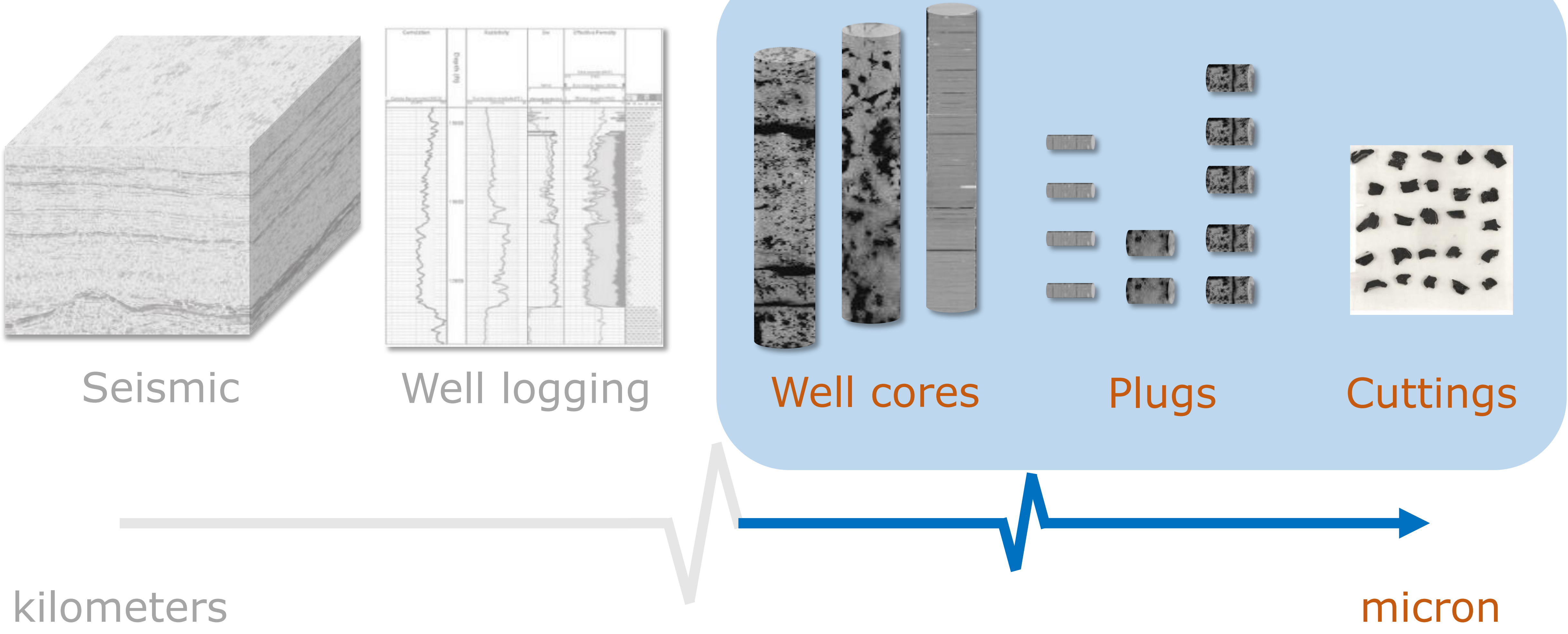
Plugs

Cuttings

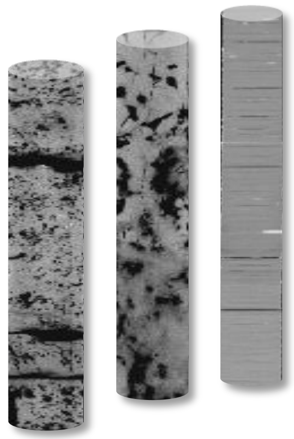
kilometers

micron

Unconventional Resources – Unconventional Information



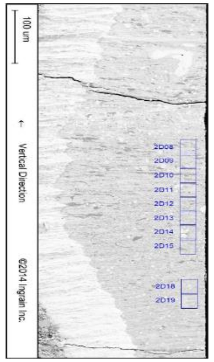
Sample Scales



Plugs

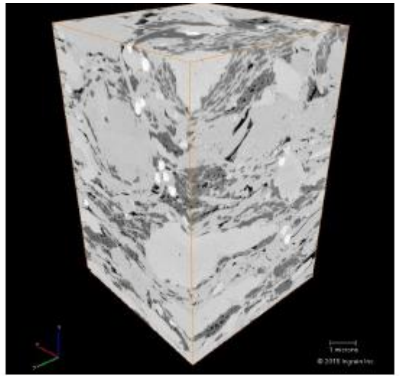
Well cores

Cuttings

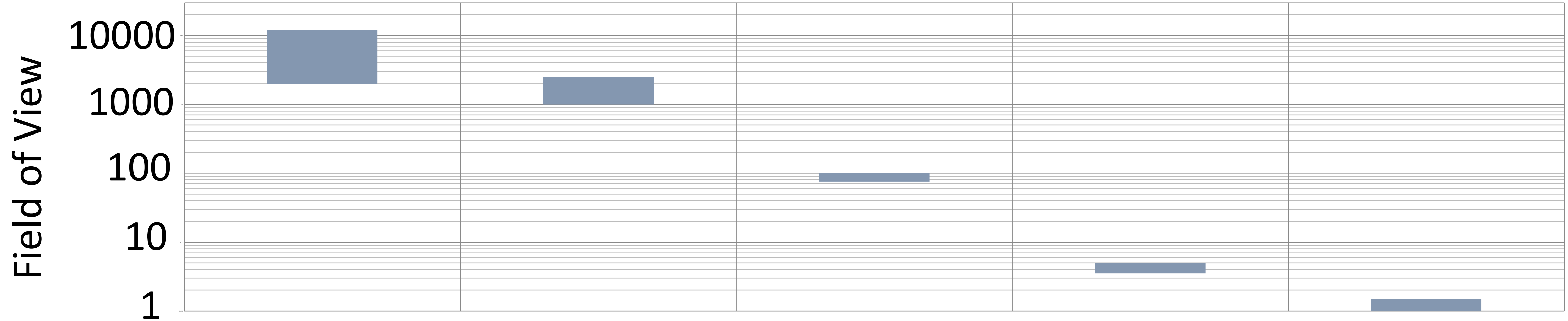


2D SEM
mm-scale

2D SEM
µm-scale



3D SEM



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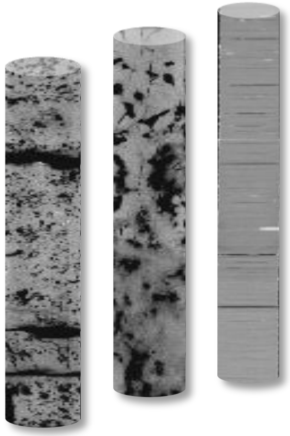
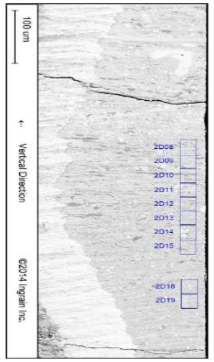
Multi-Scale Imaging



Plugs

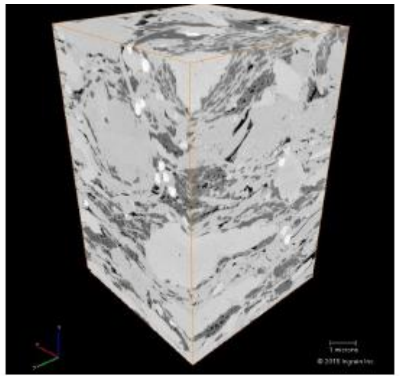
Well cores

Cuttings



2D SEM
mm-scale

2D SEM
µm-scale



3D SEM

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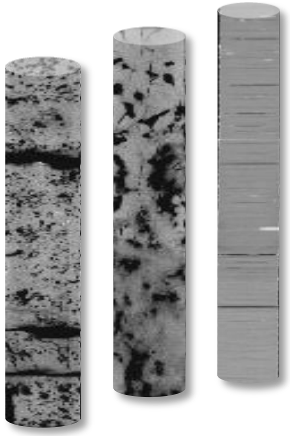
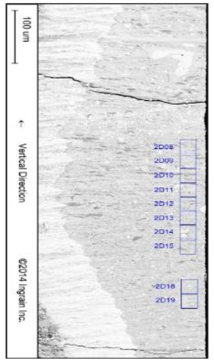
Rock Properties Upscaling



Well cores

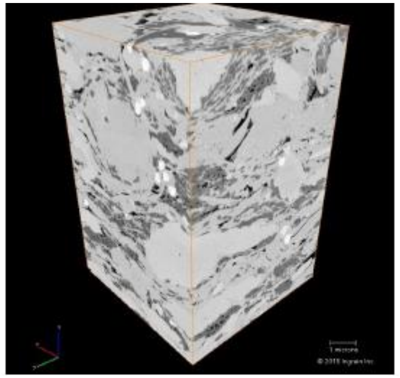
Plugs

Cuttings



2D SEM
mm-scale

2D SEM
µm-scale



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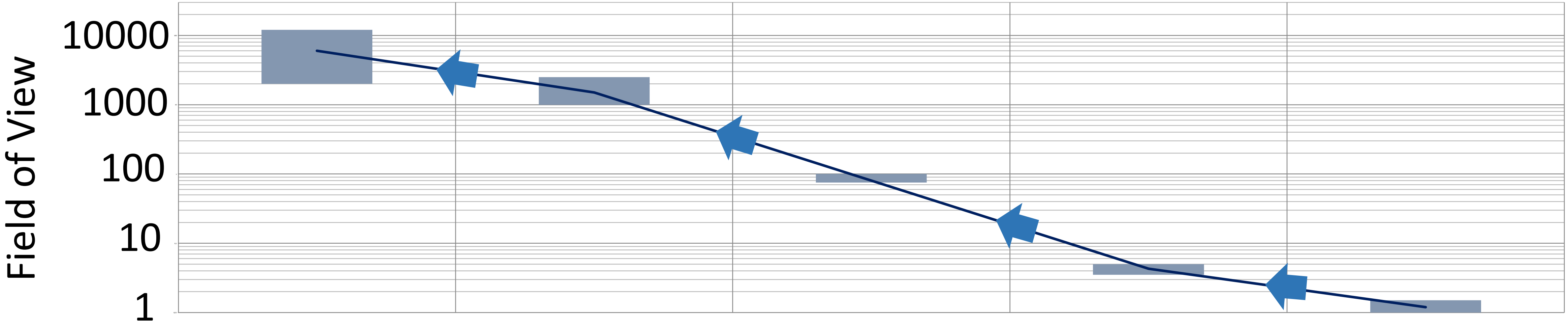
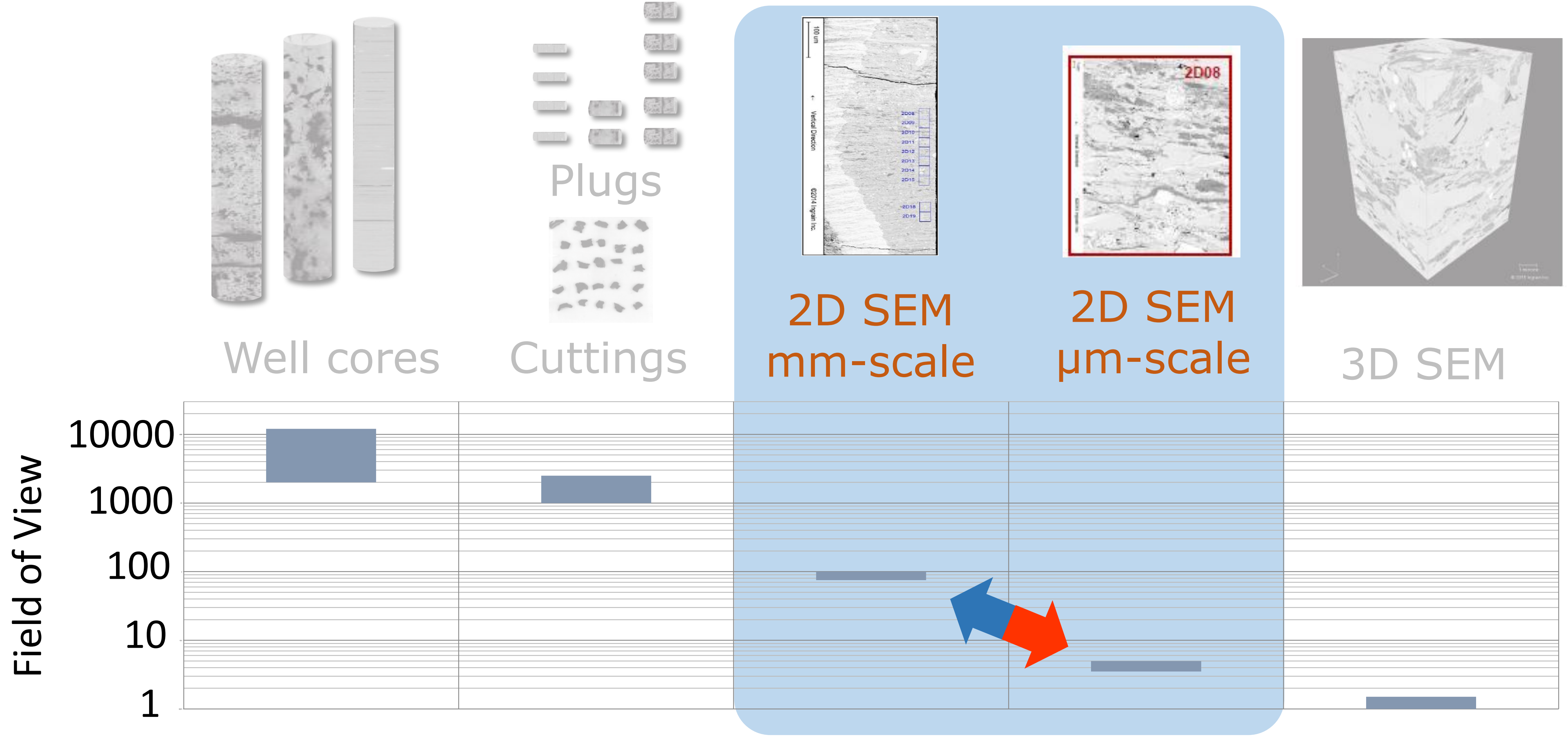


Two-Scale Characterization



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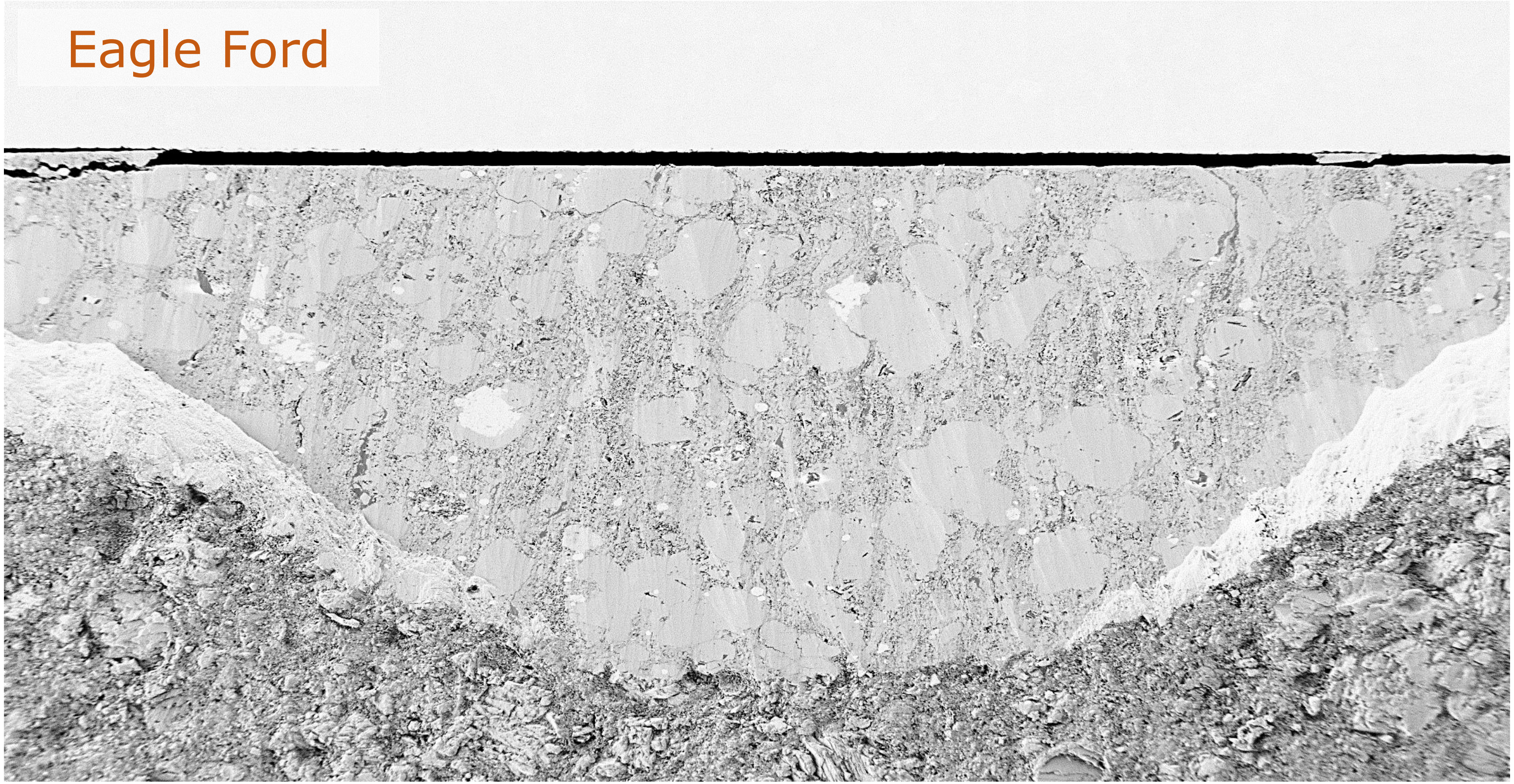
2D SEM mm-scale



1 mm

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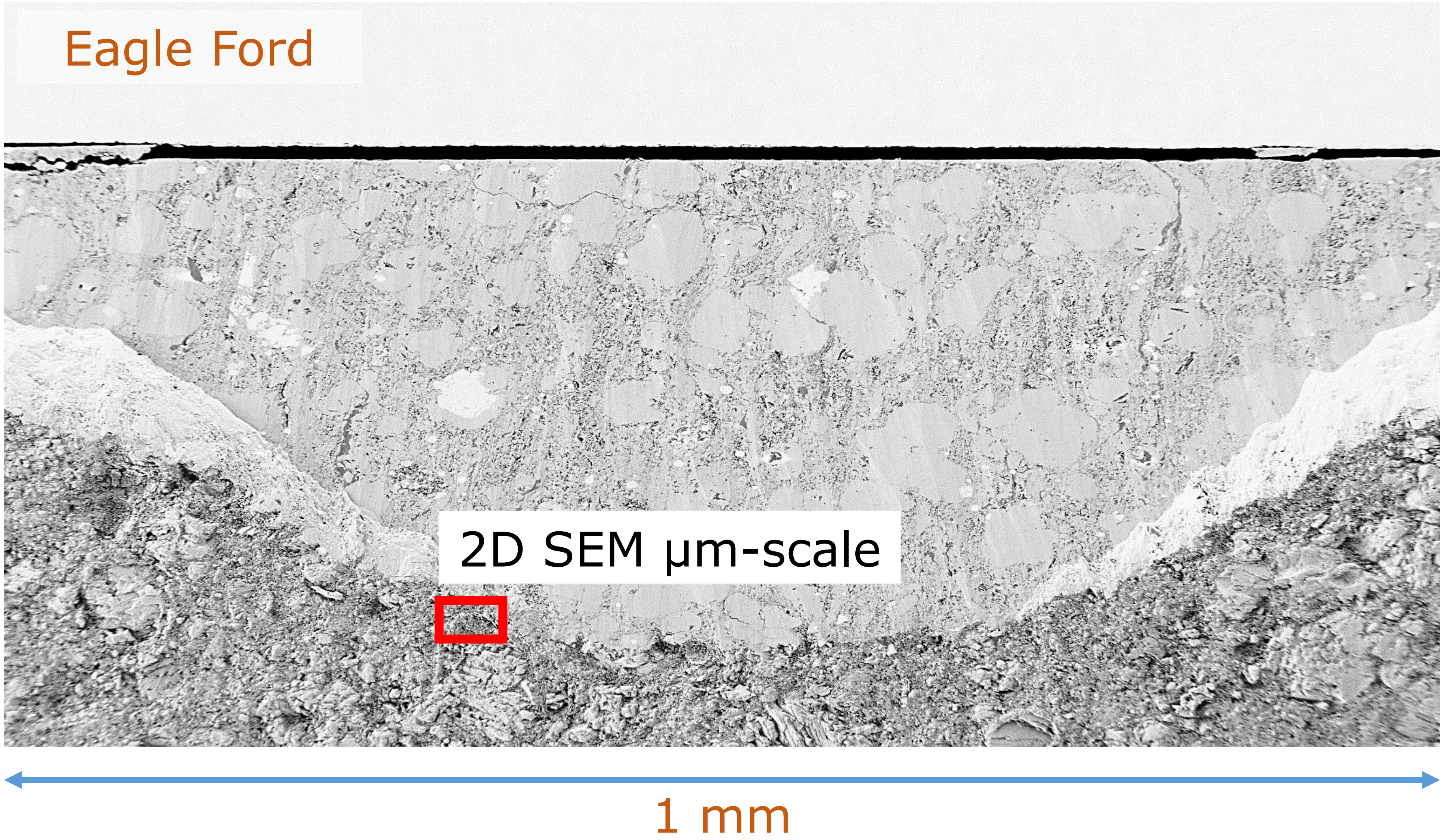
2D SEM mm-scale



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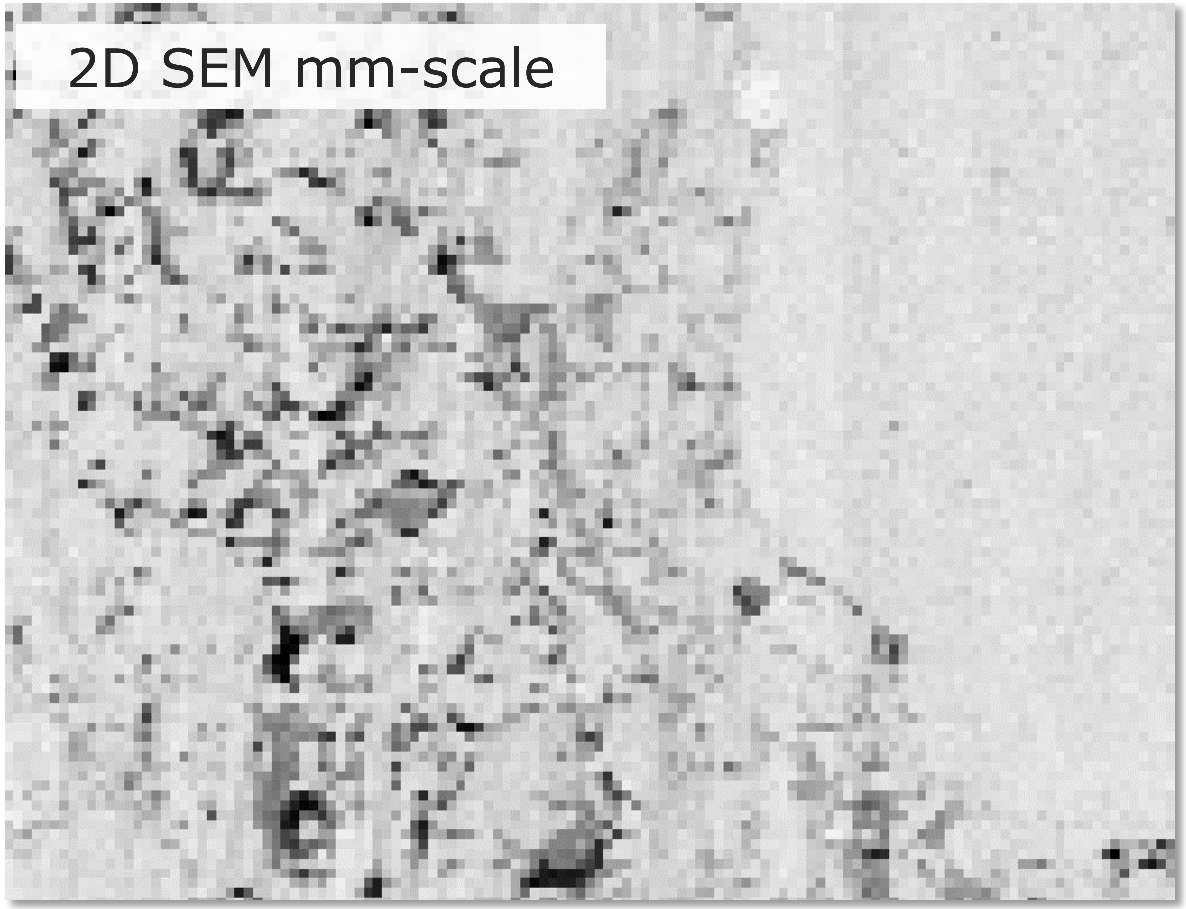
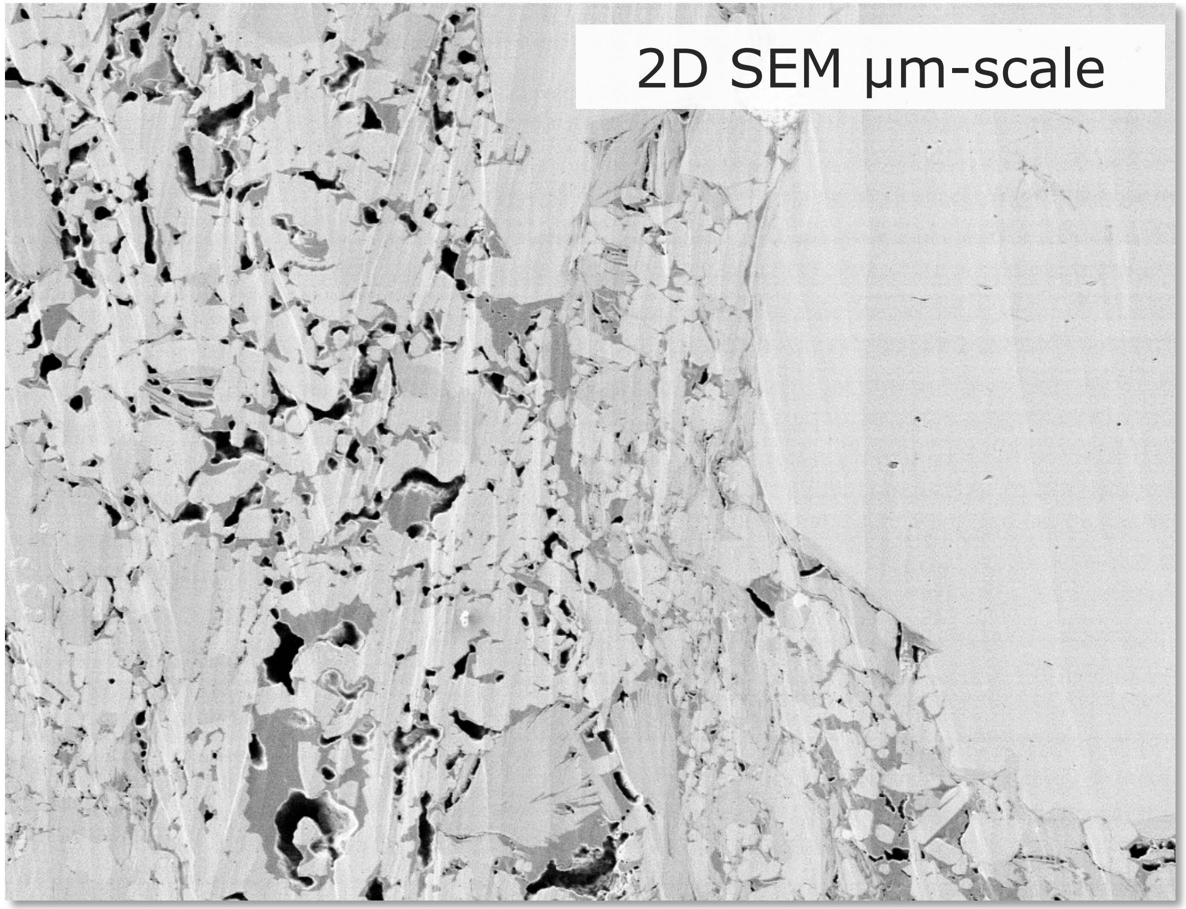
2D SEM mm-scale vs. 2D SEM µm-scale





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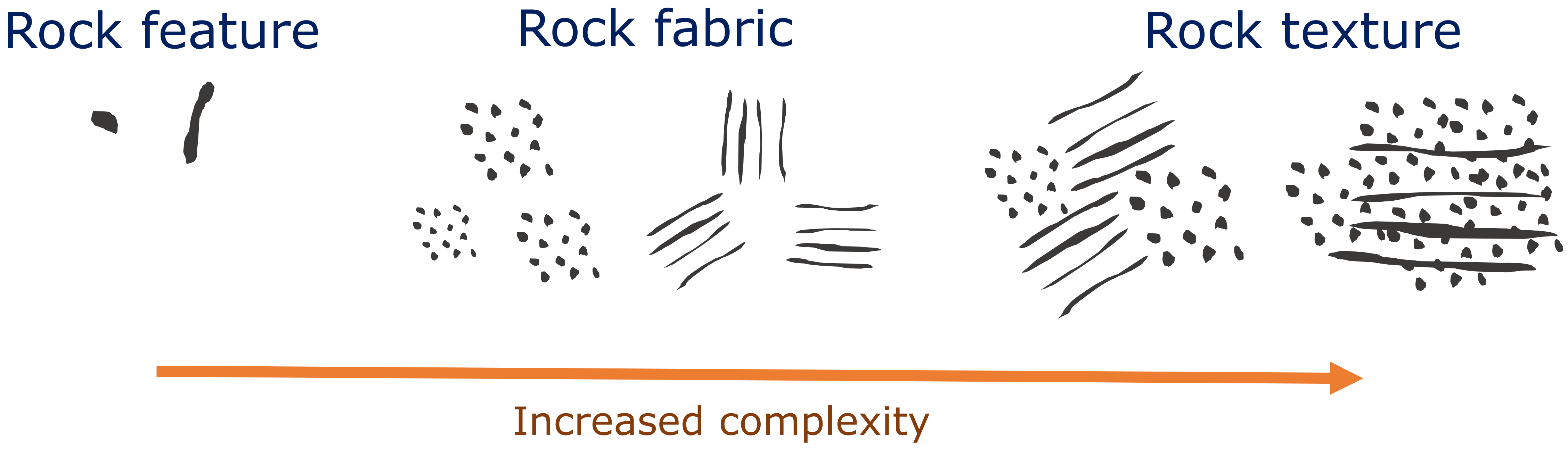
Building Blocks



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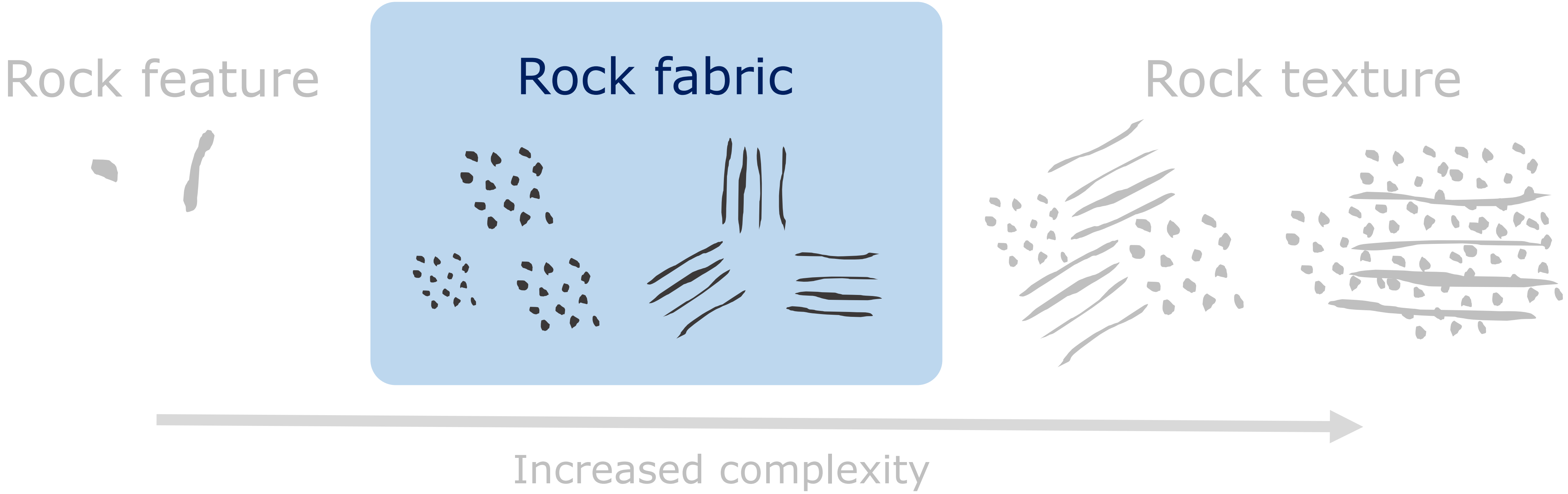
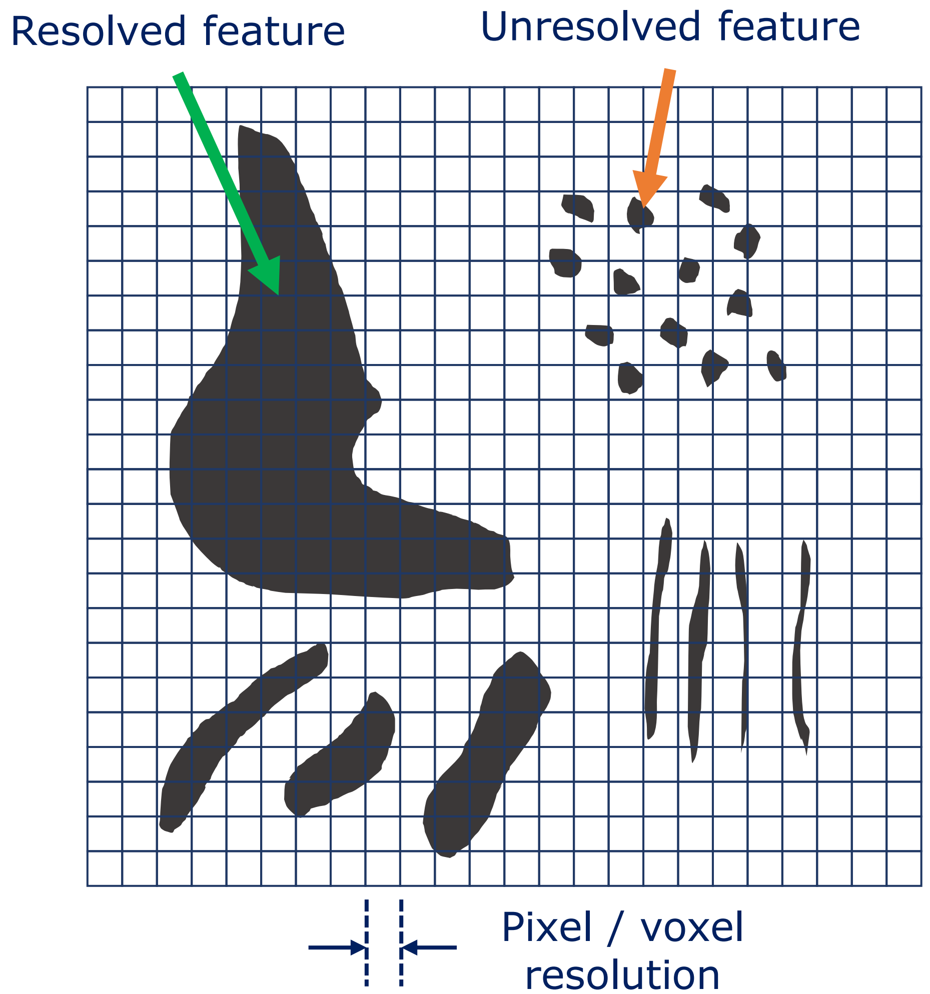
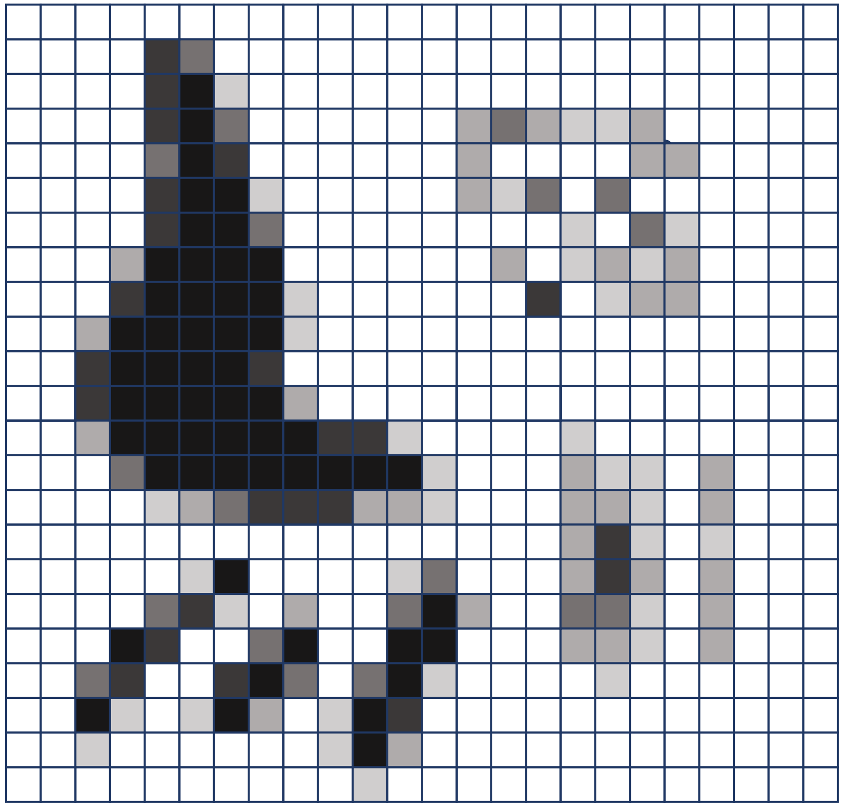
Building Blocks

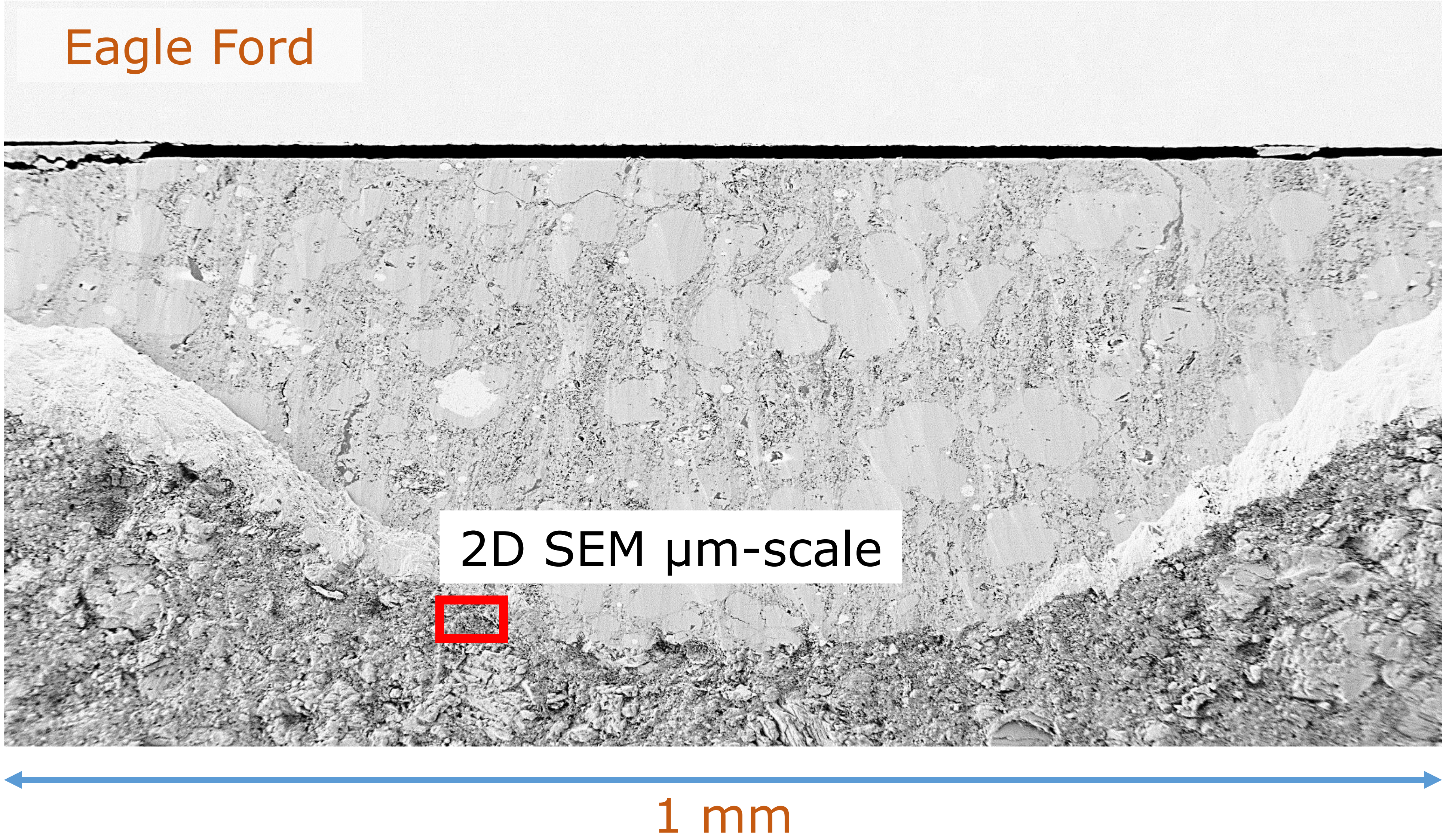


Real vs. Digitalized Image

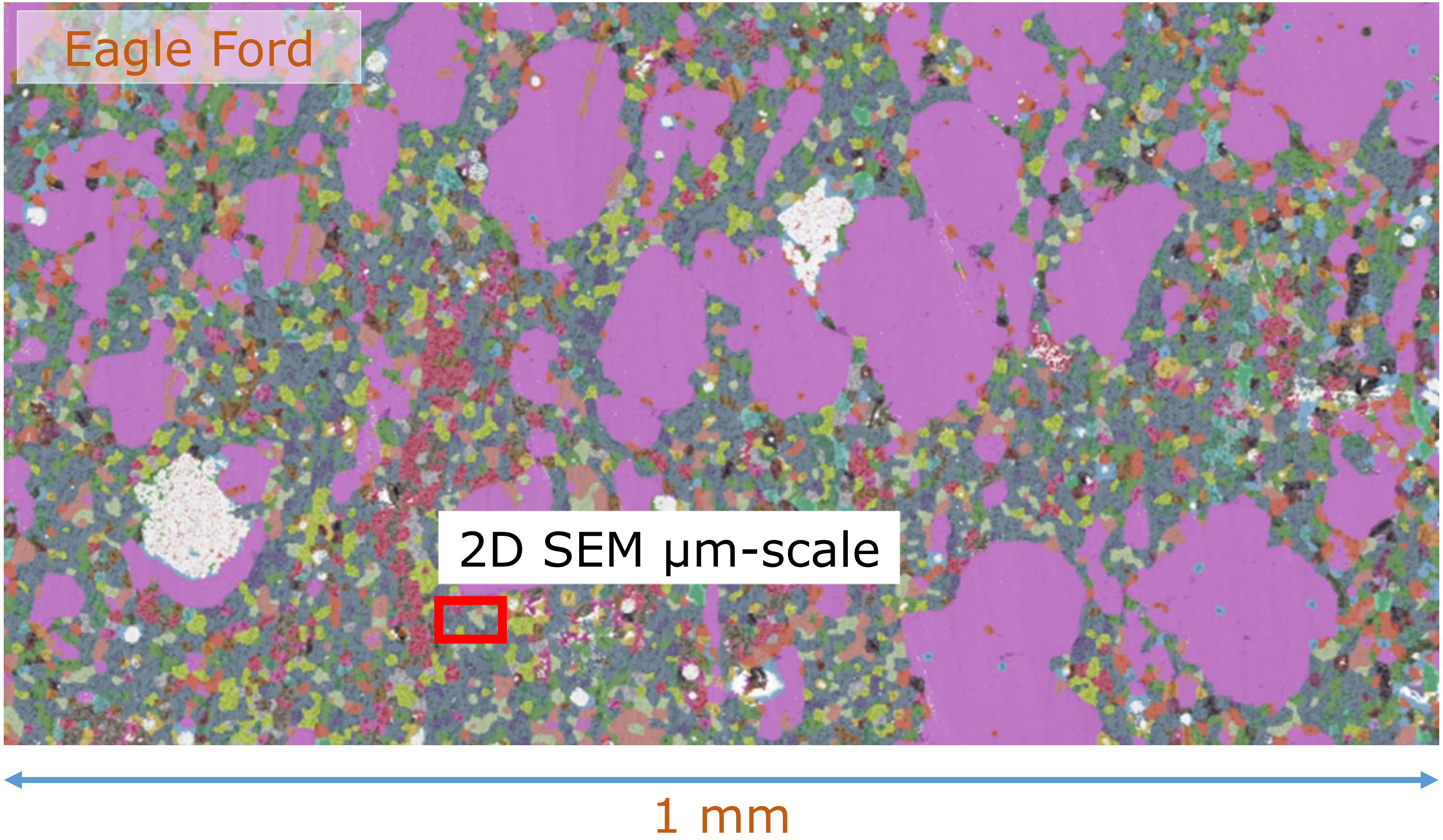


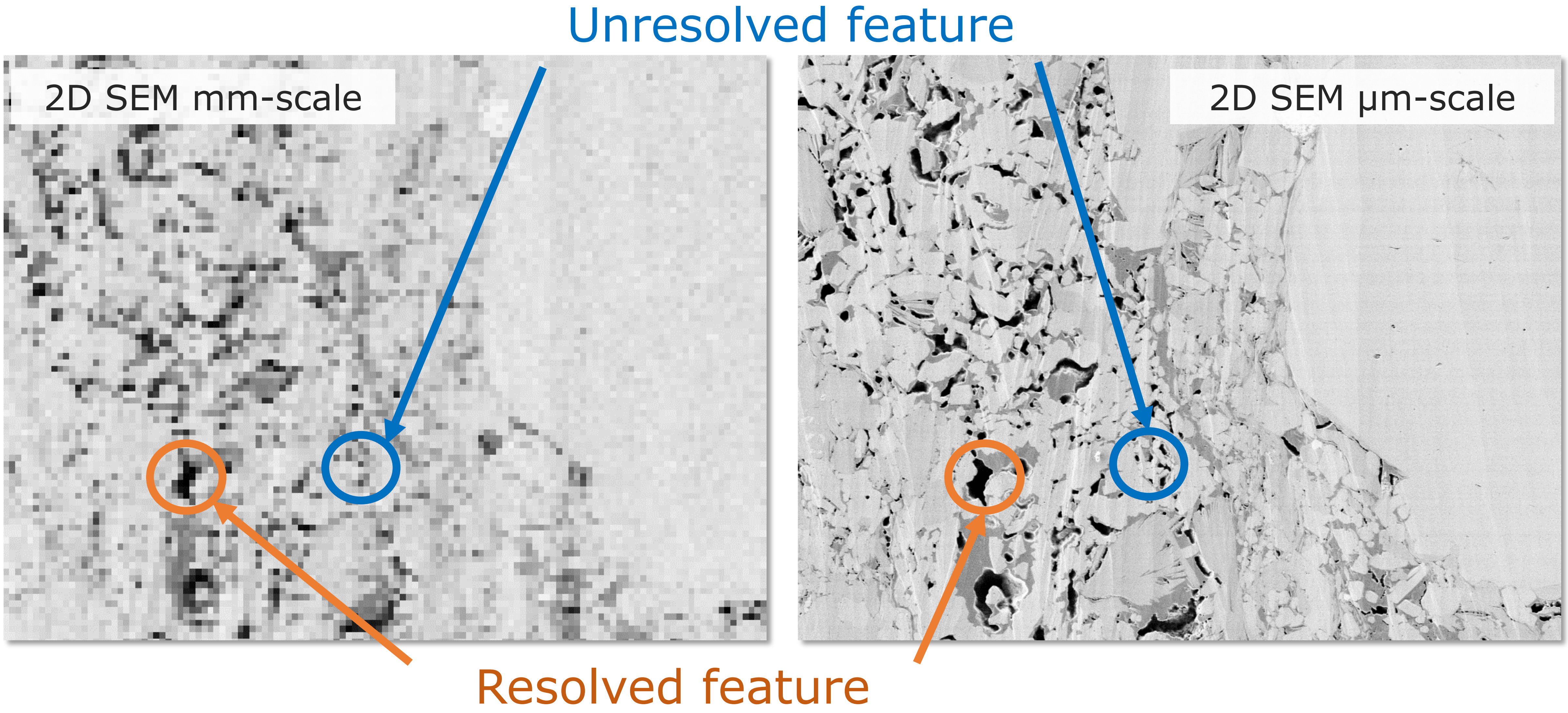


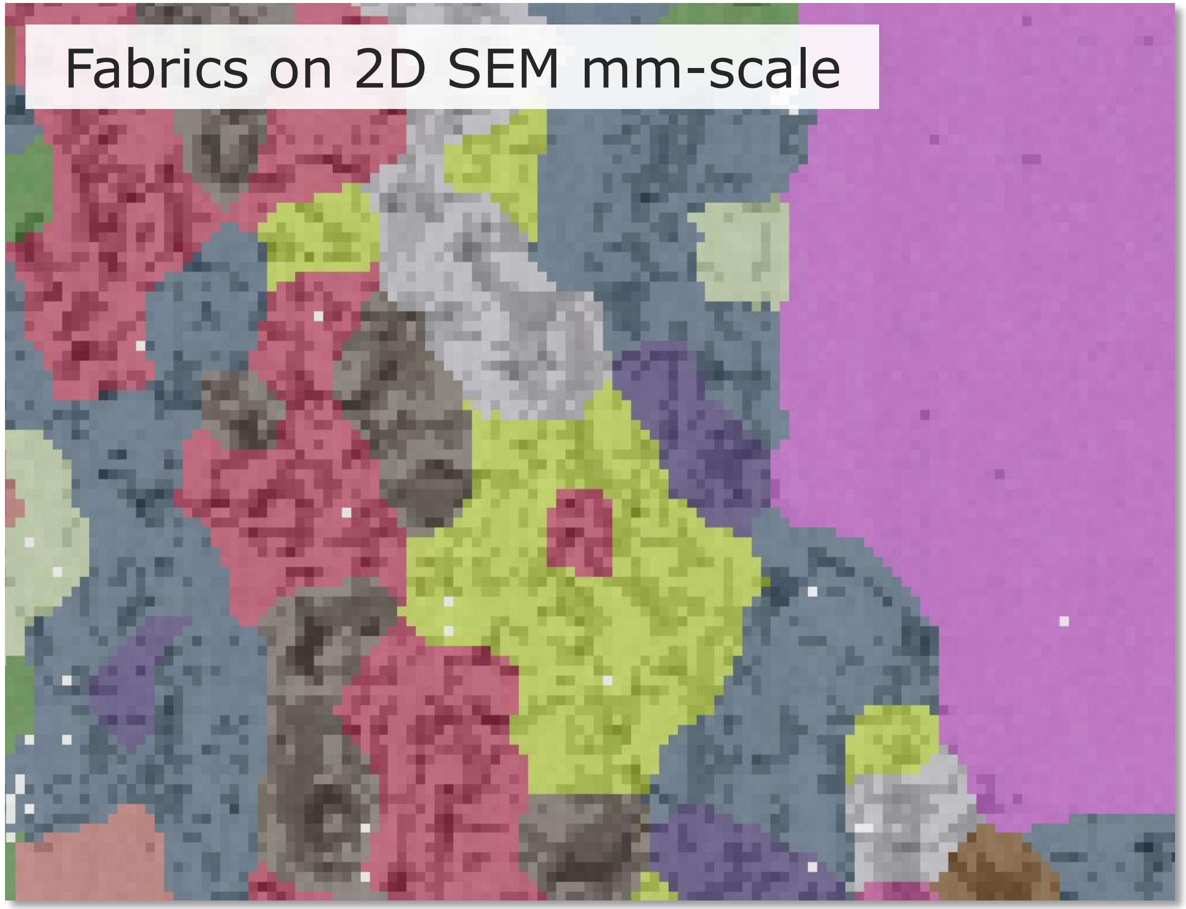
2D SEM mm-scale

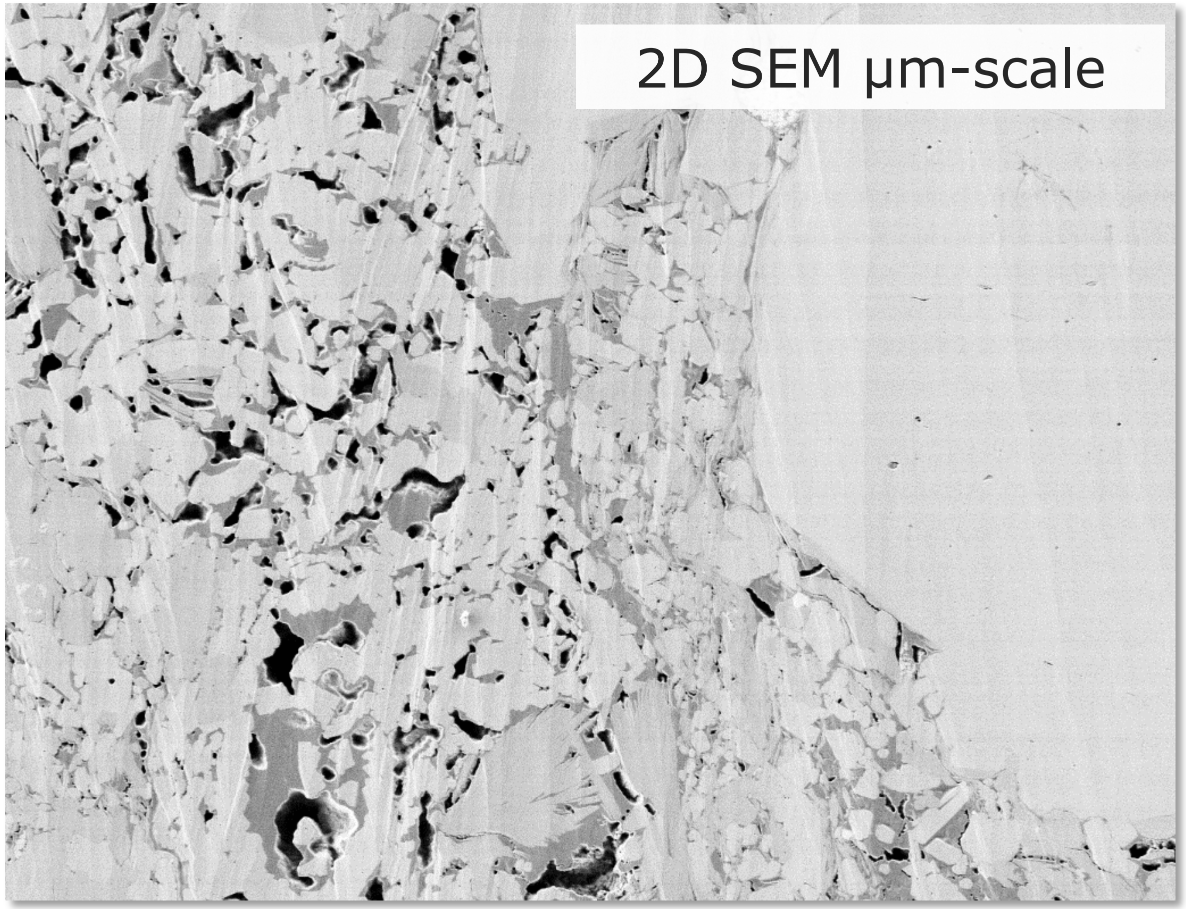


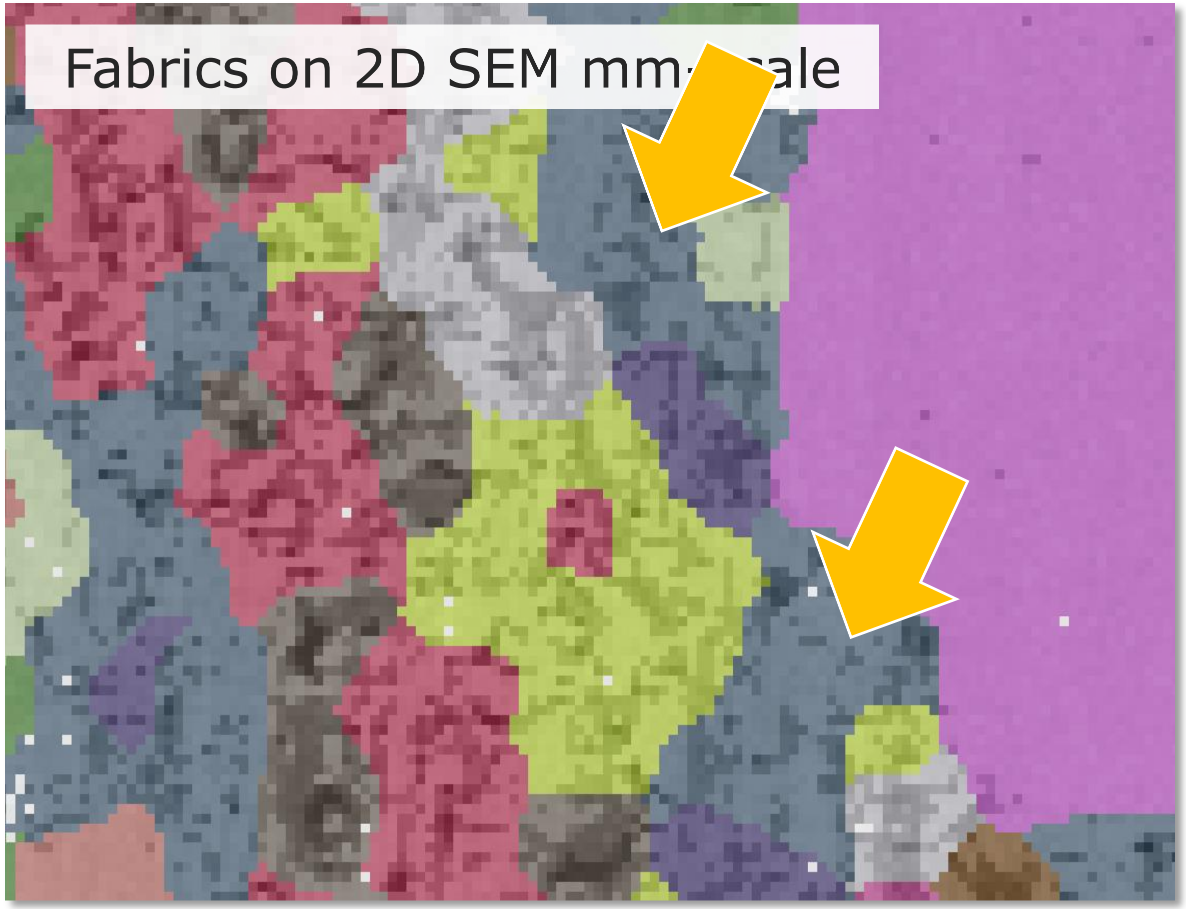
2D SEM mm-scale: Fabrics

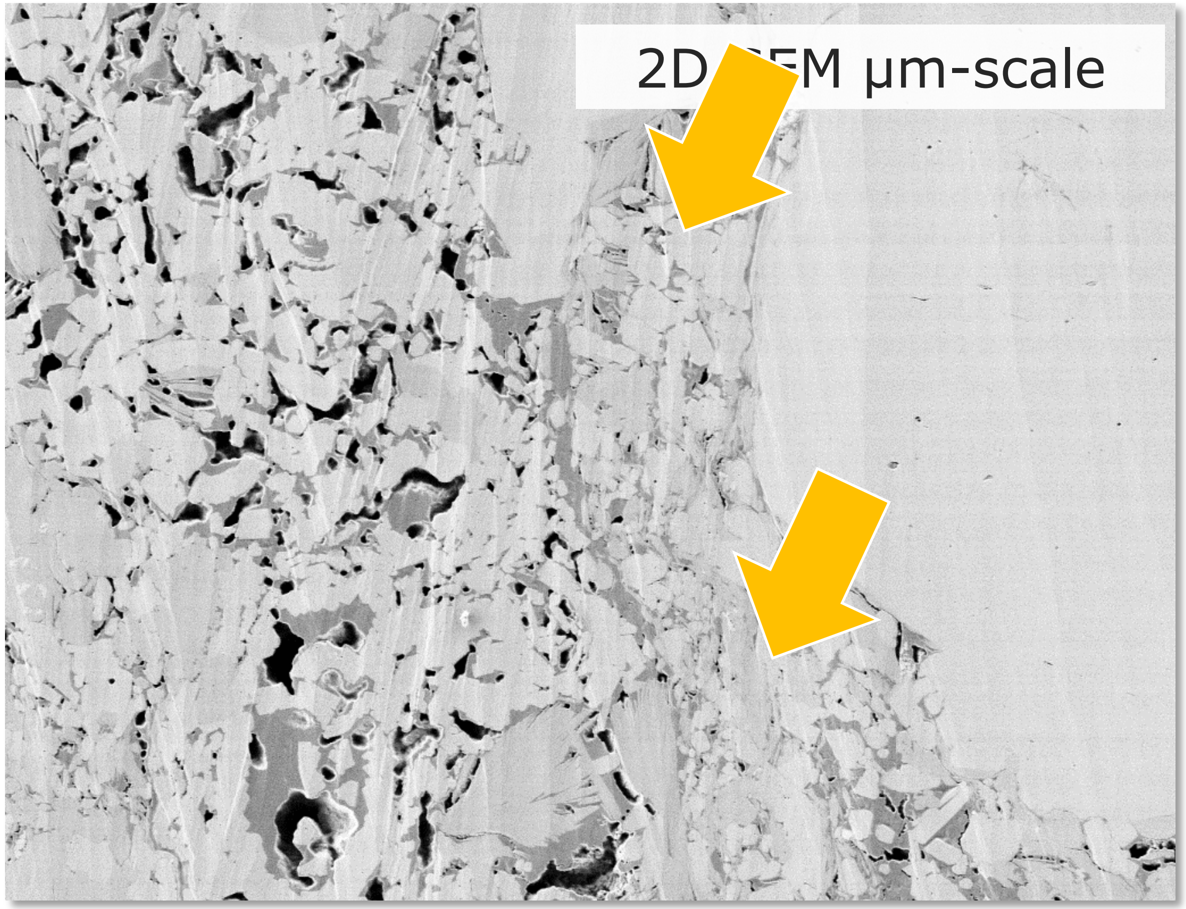



Unresolved feature
2D SEM mm-scale
2D SEM µm-scale
Resolved feature

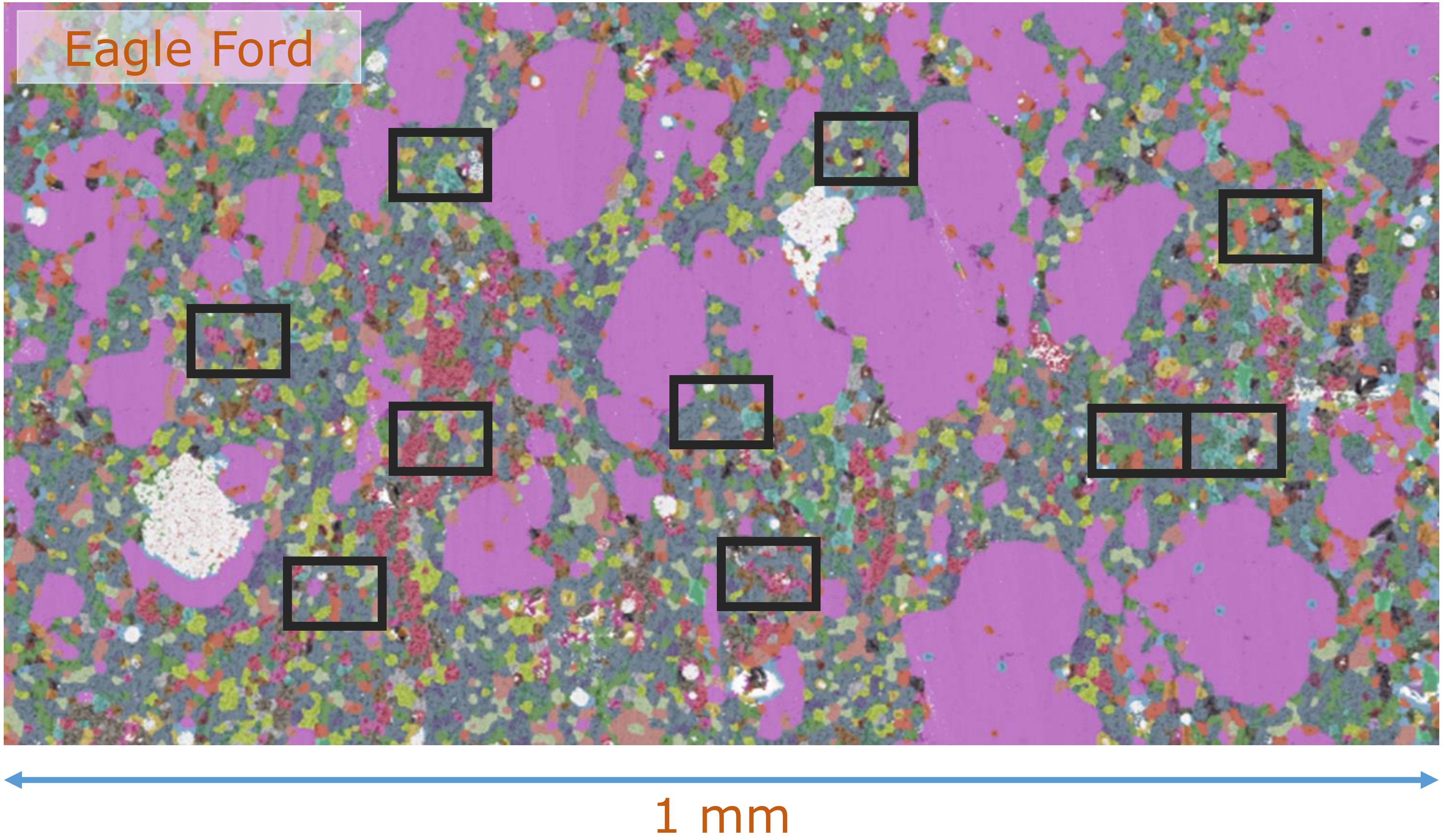

Fabrics on 2D SEM mm-scale


2D SEM µm-scale

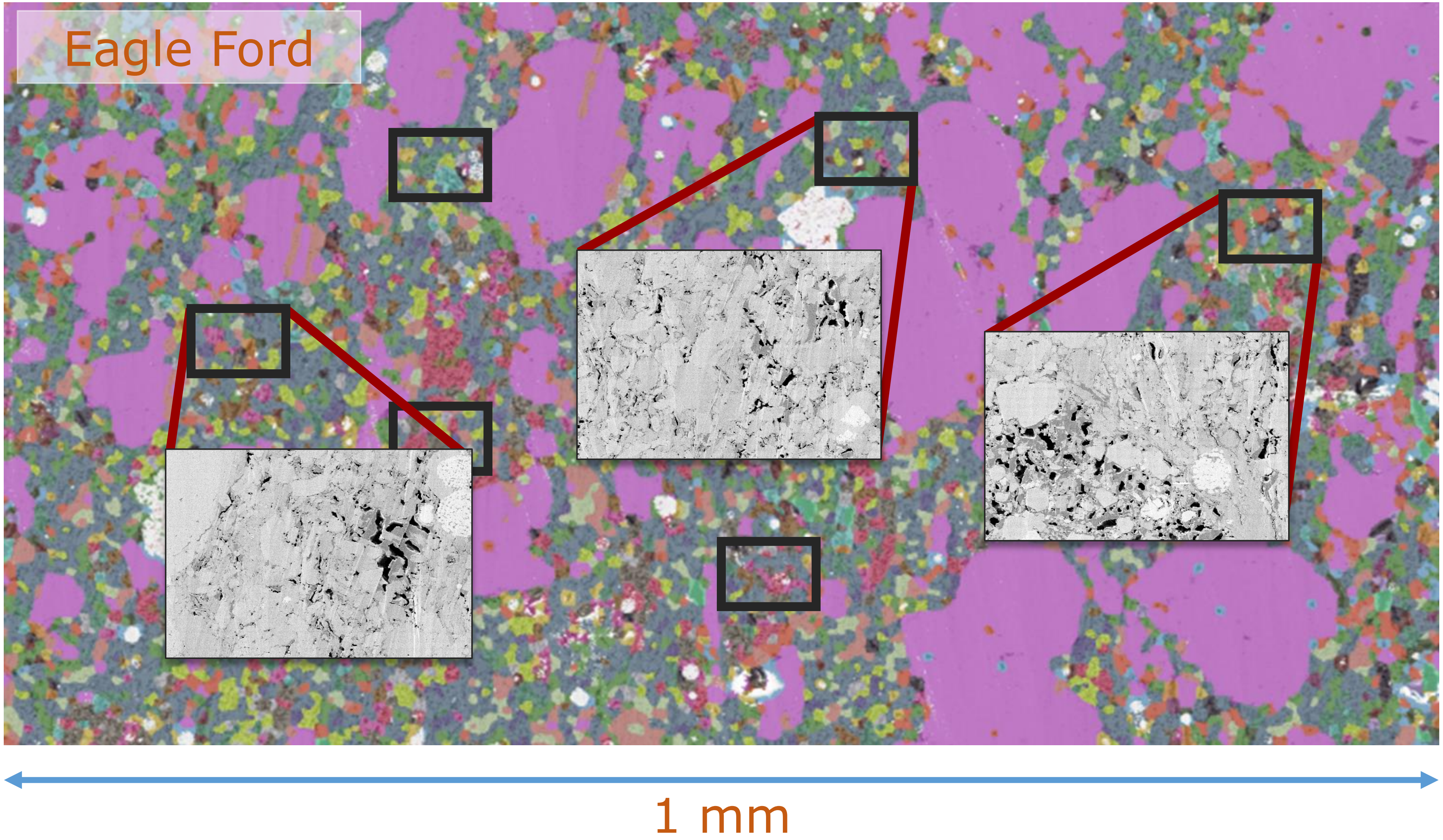

Fabrics on 2D SEM mm- ale

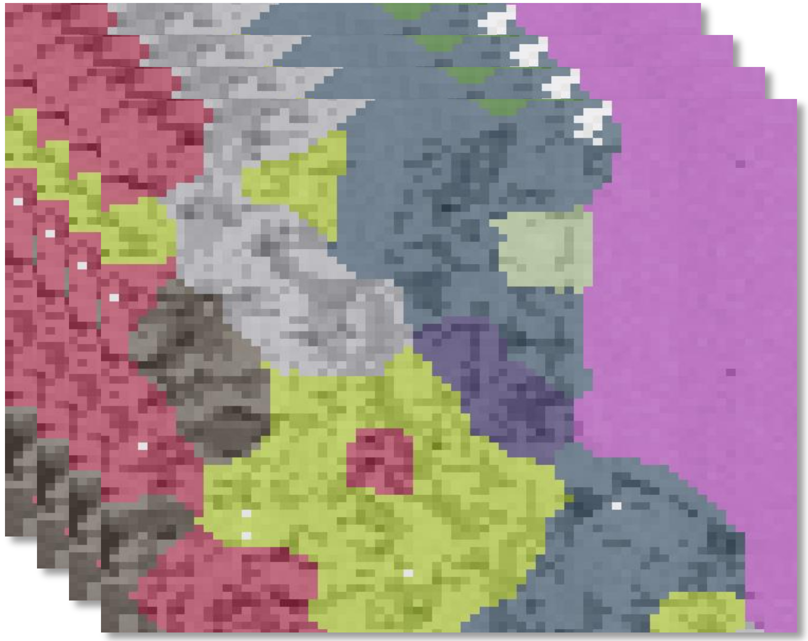

2D EM µm-scale

2D SEM mm-scale: Fabrics & Samplings

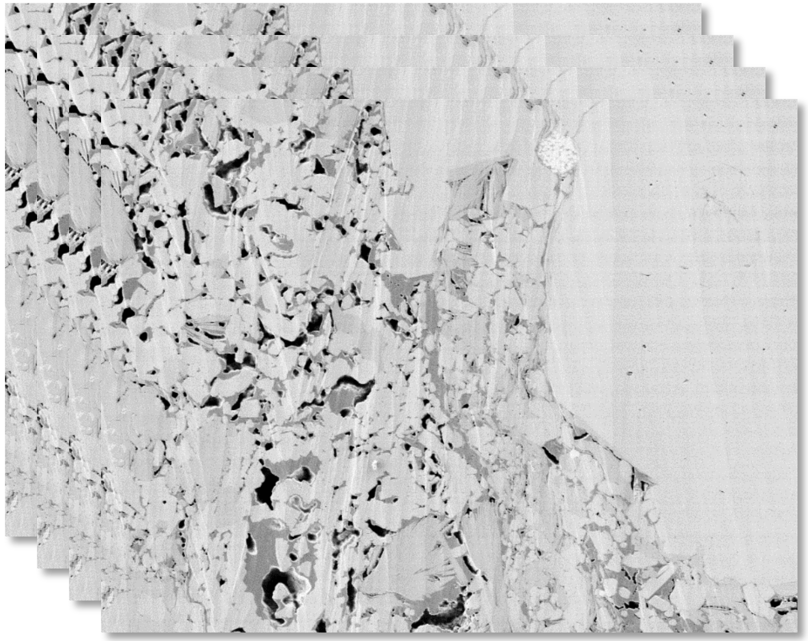


2D SEM mm-scale: Fabrics & Samplings

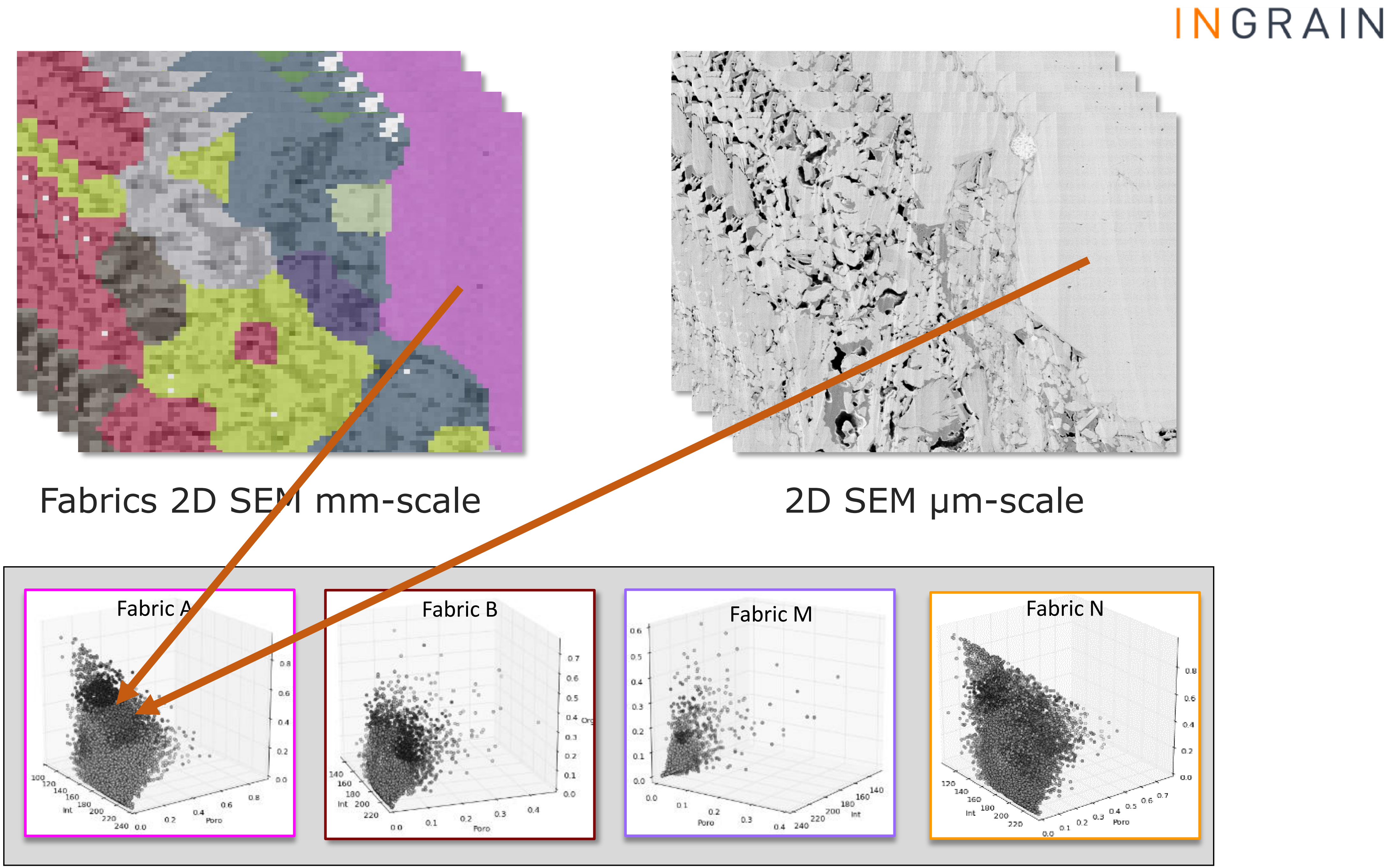




Fabrics 2D SEM mm-scale



2D SEM μm-scale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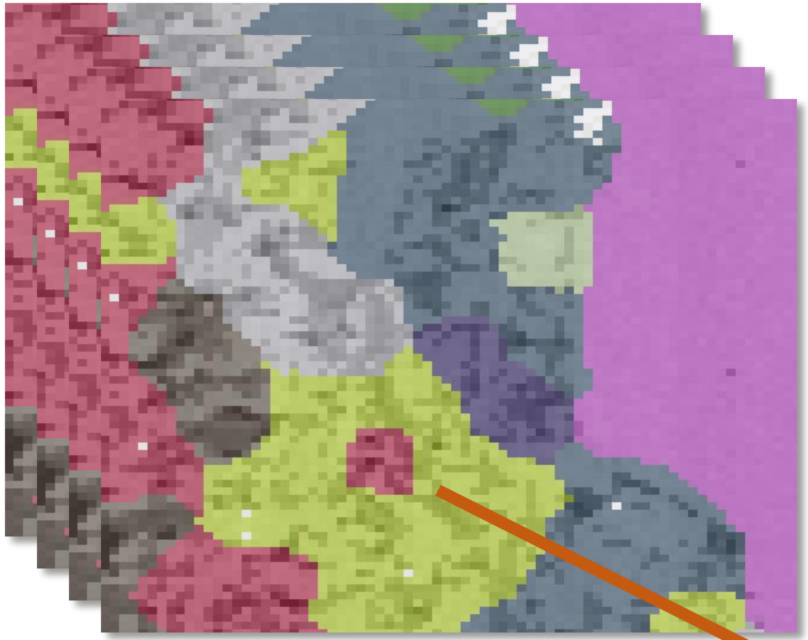
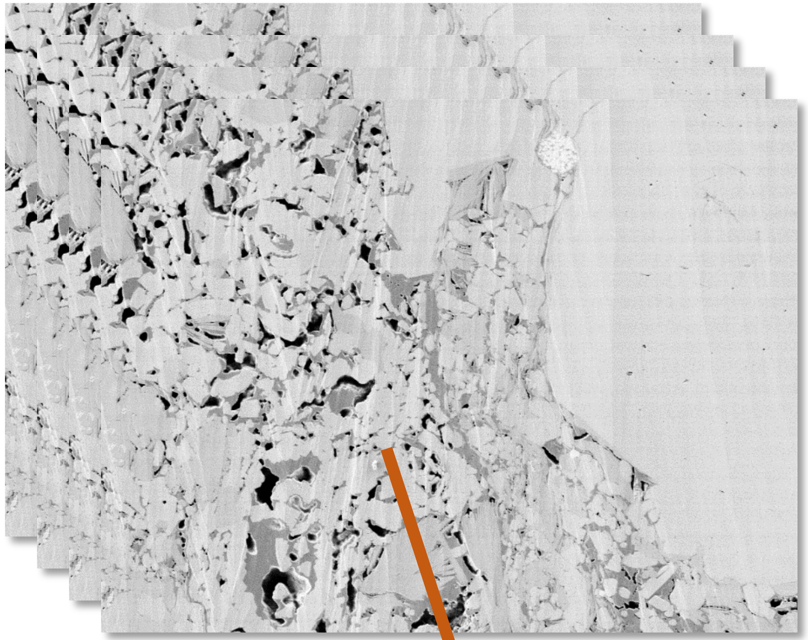
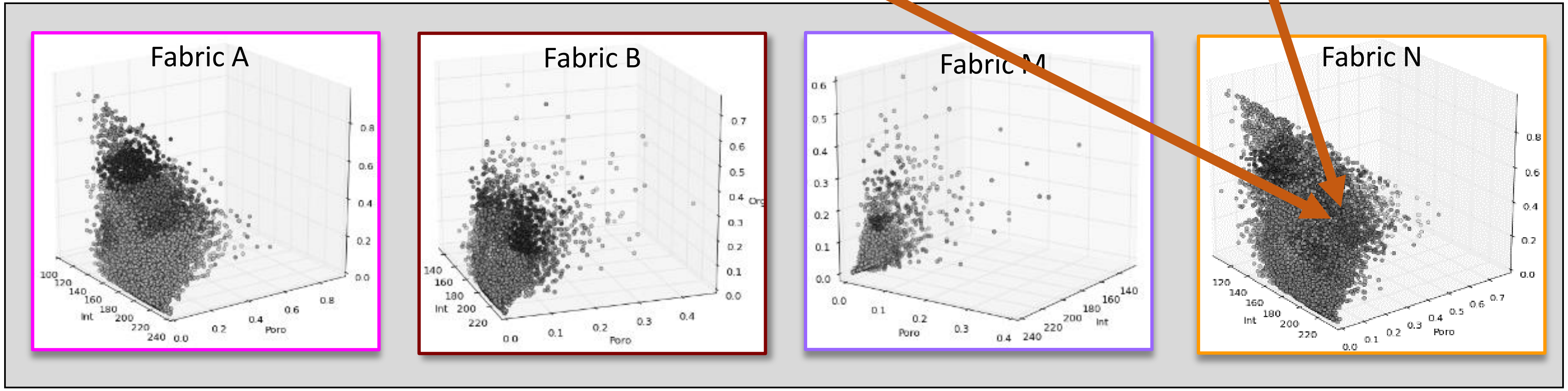
Fabrics 2D SEM mm-scale
2D SEM µm-scale
Fabric A
Fabric B
Fabric M
Fabric N
Int
Poro



Fabrics 2D SEM mm-scale



2D SEM µm-scale



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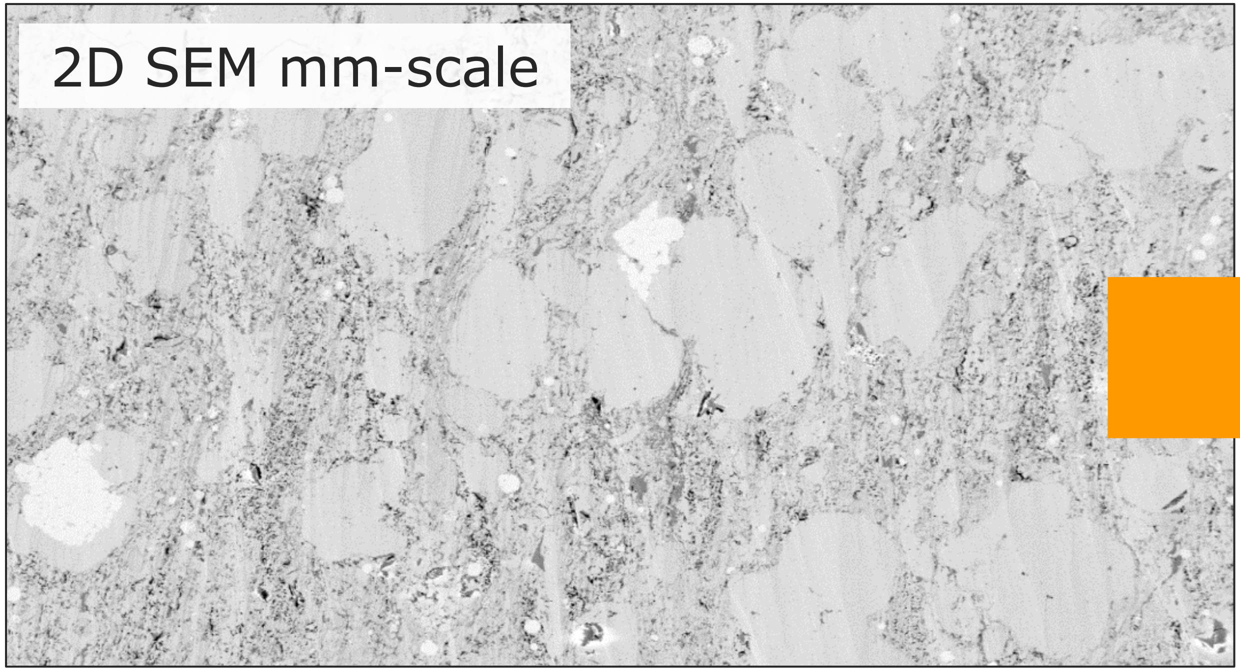
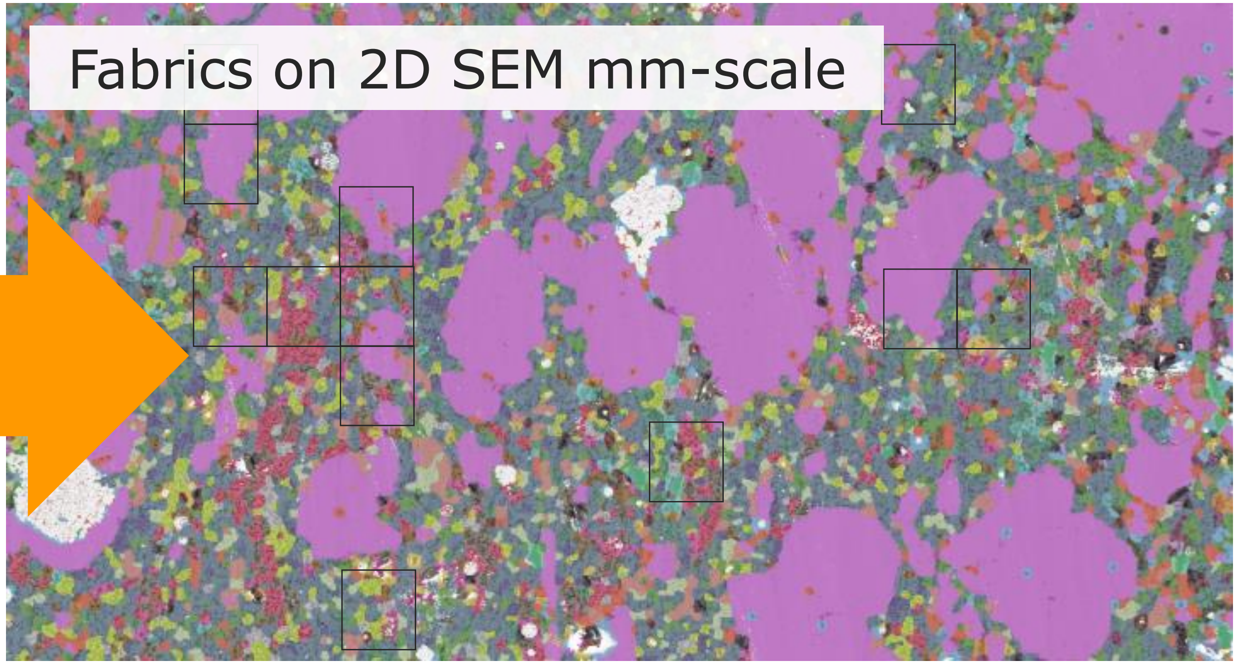
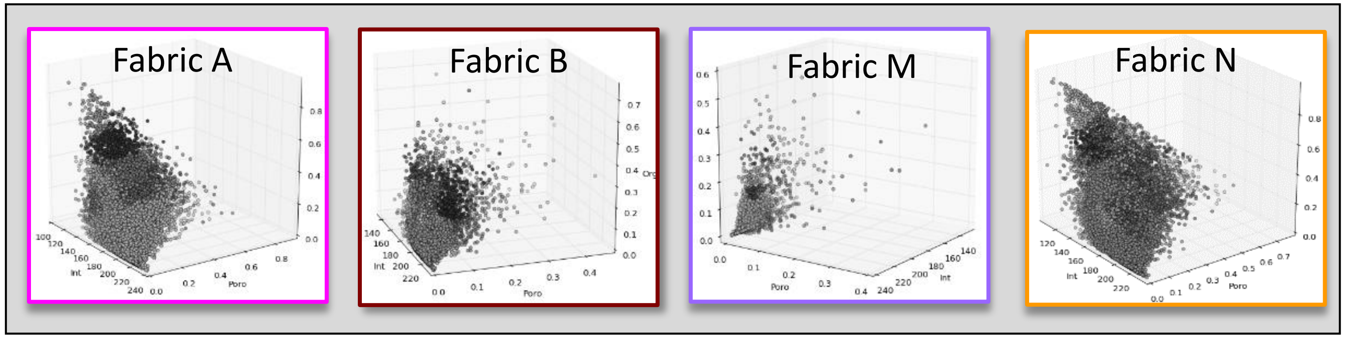
Multi-Scale Imaging and Upscaling







Multi-Scale Statistics

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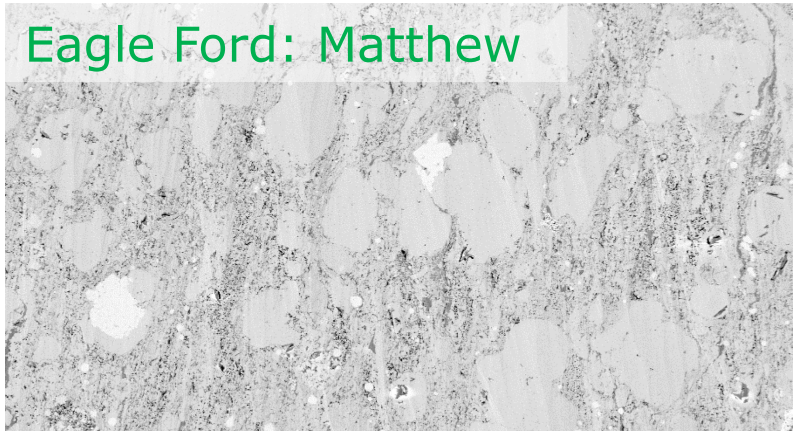
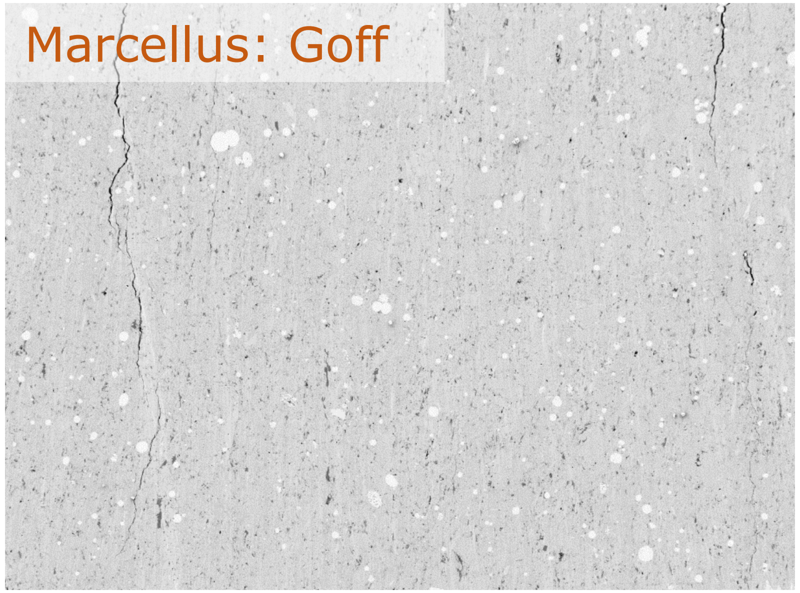

Eagle Ford: Matthew

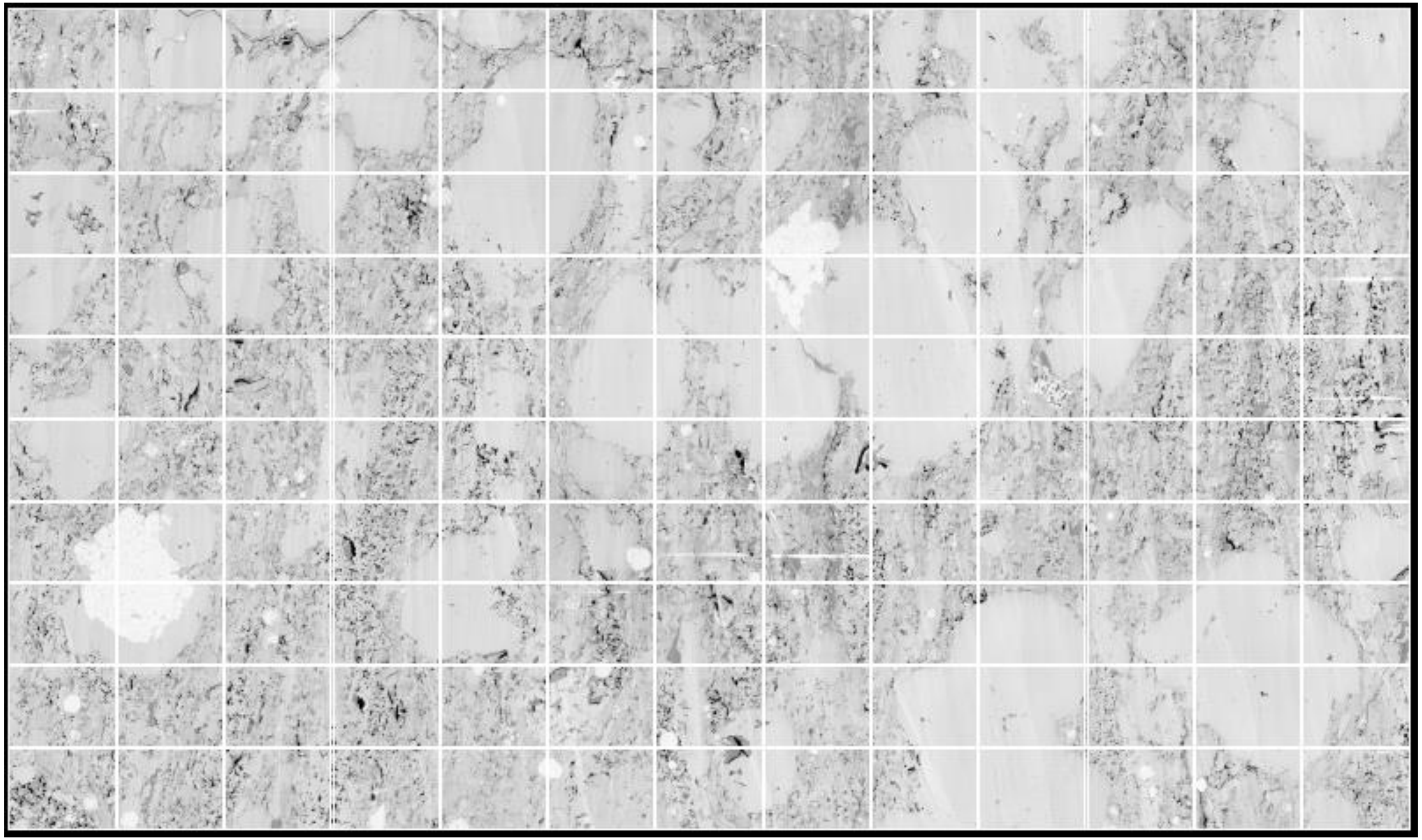

Marcellus: Armstrong


Bakken: Burbank A

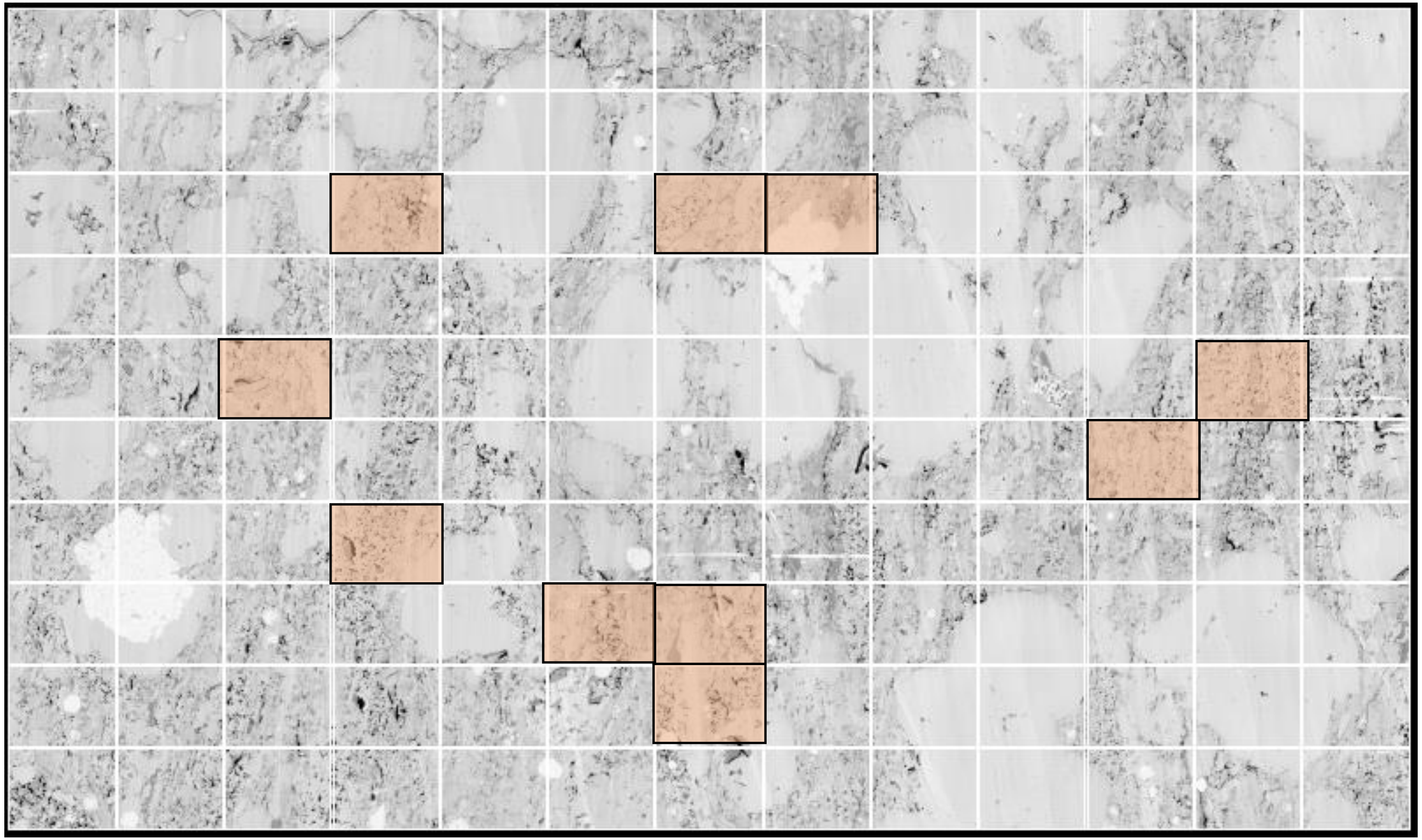

Marcellus: Goff


Bakken: Burbank B

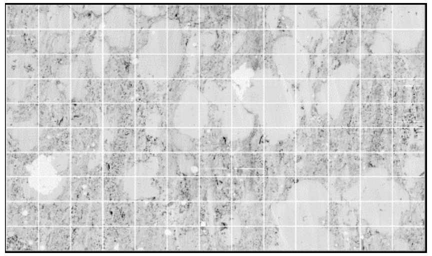
Mosaic Properties (~100 2D µm SEM images)

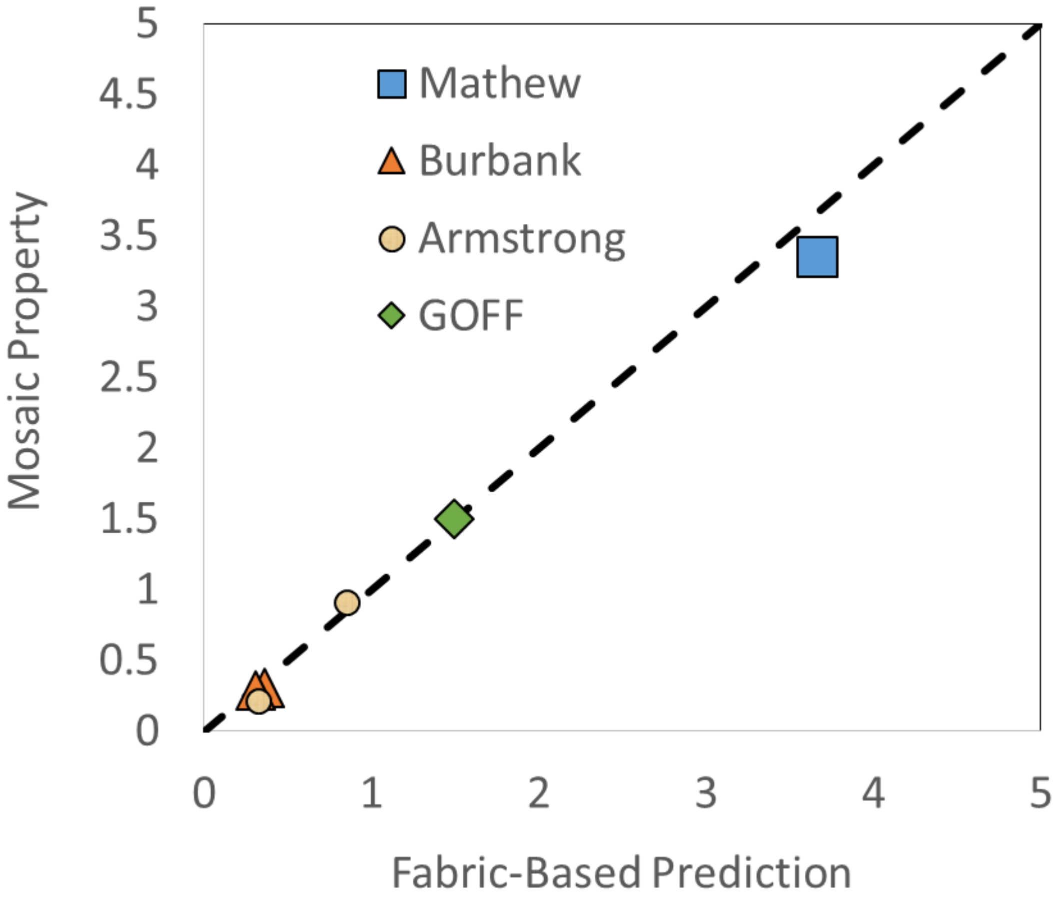


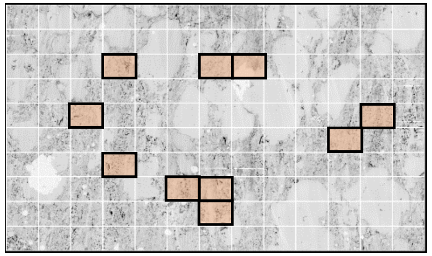
Fabrics-Based Upscaled Properties (~10 2D µm SEM images)



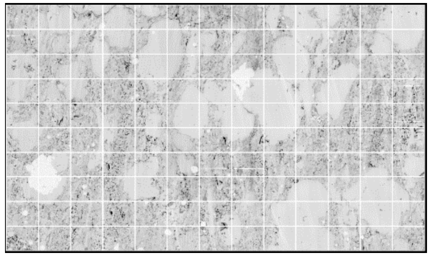
Rock Porosity

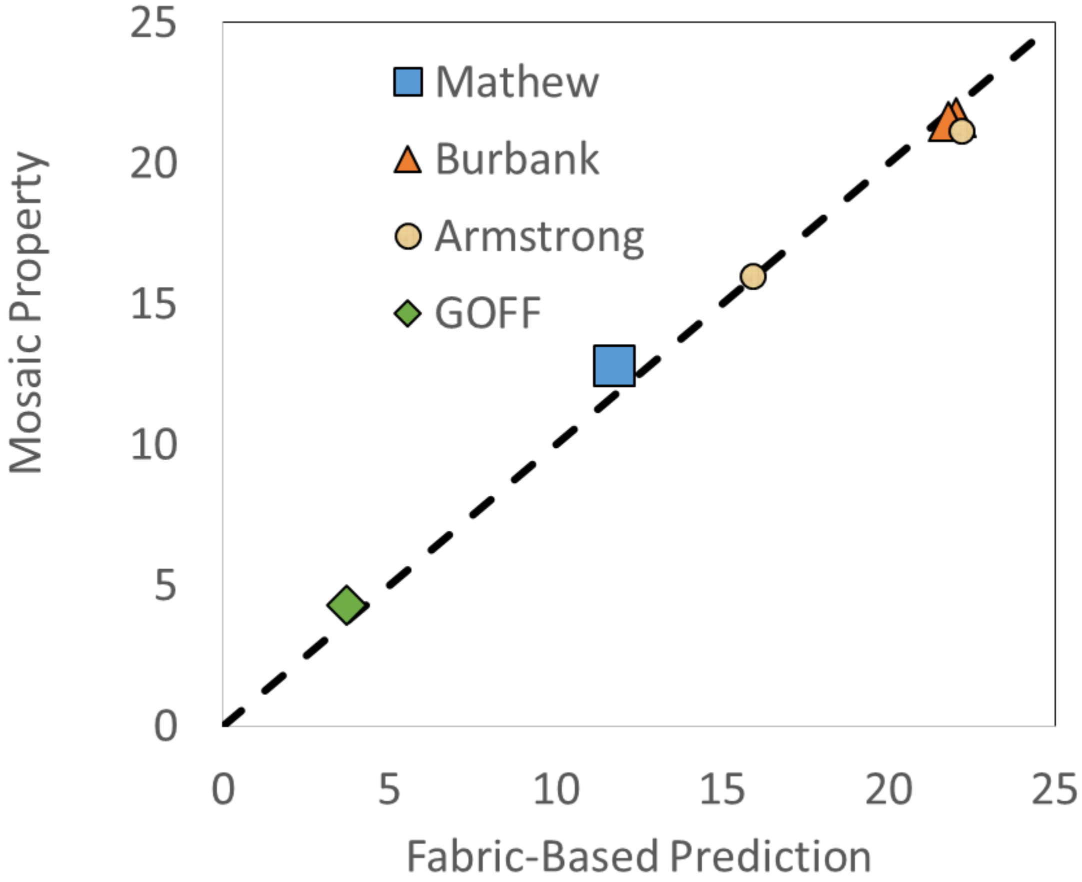


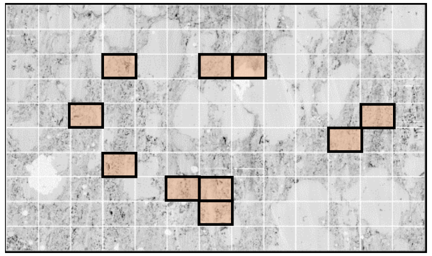




Rock Organic Fraction







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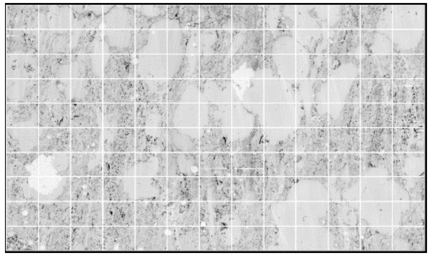
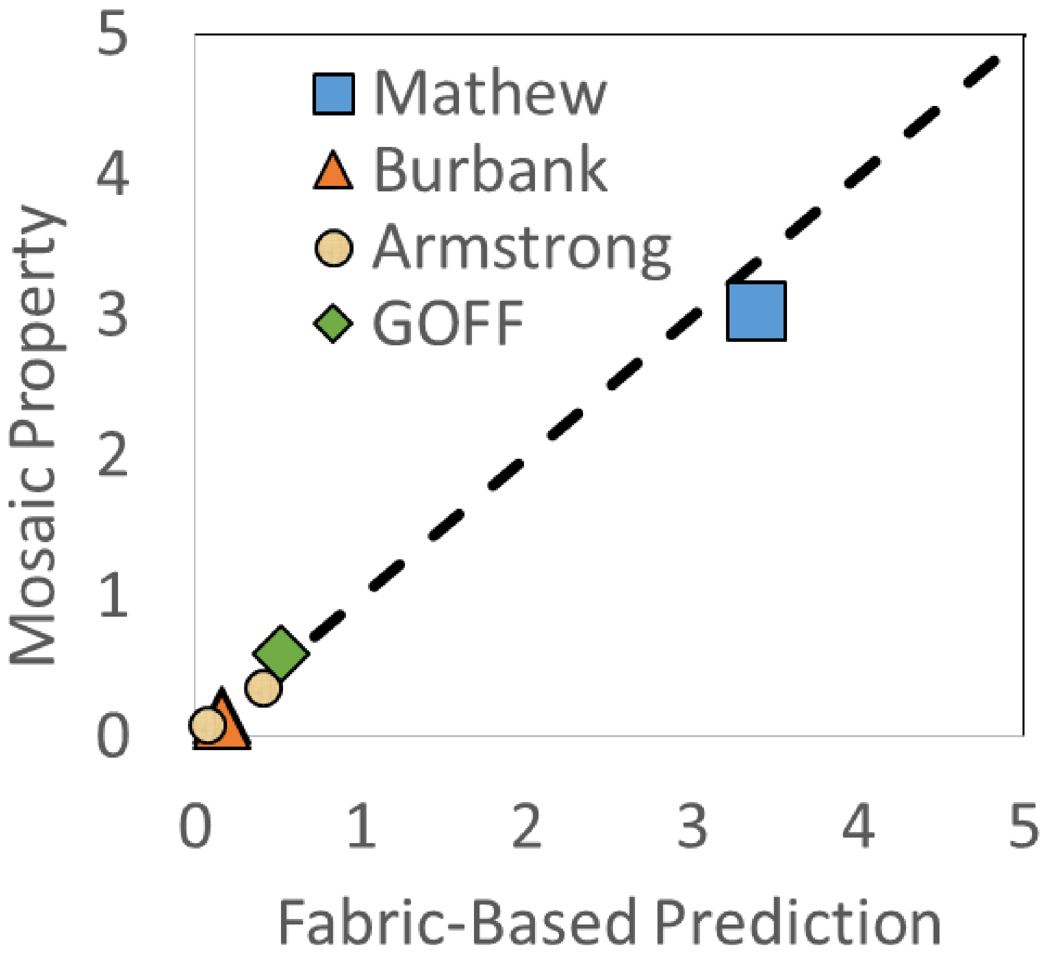
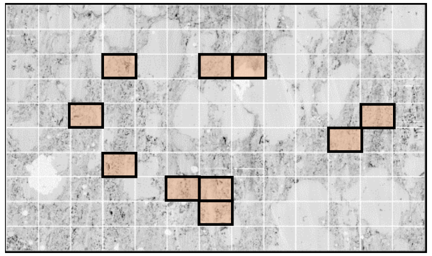
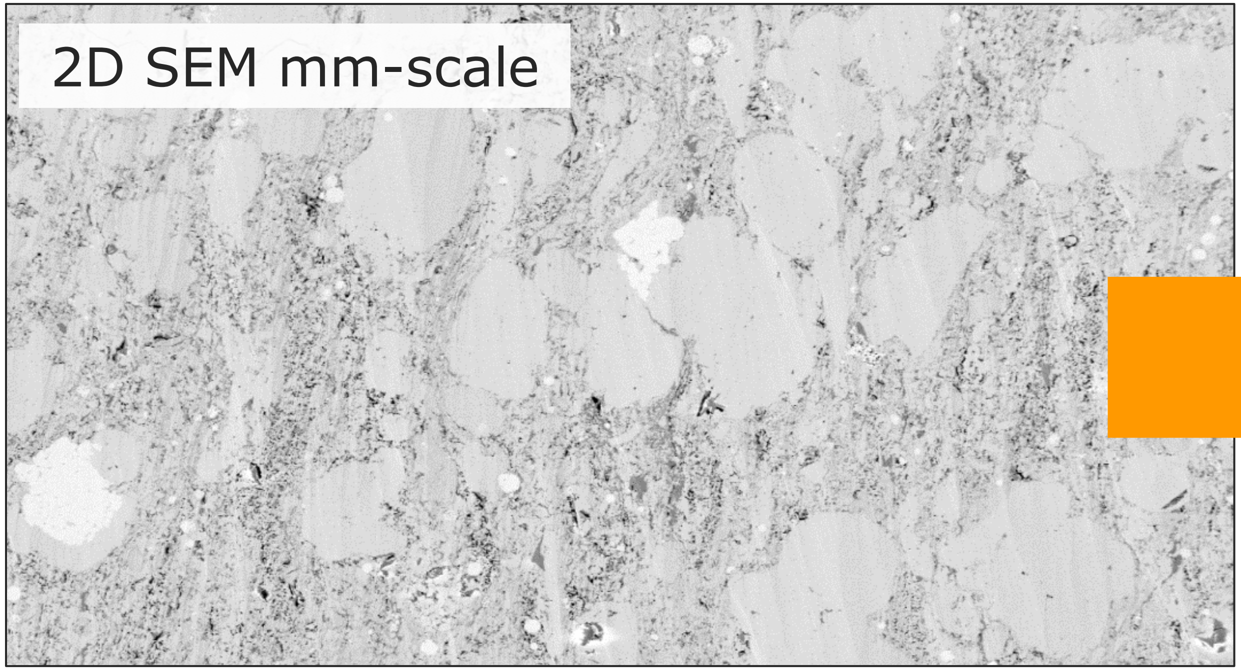
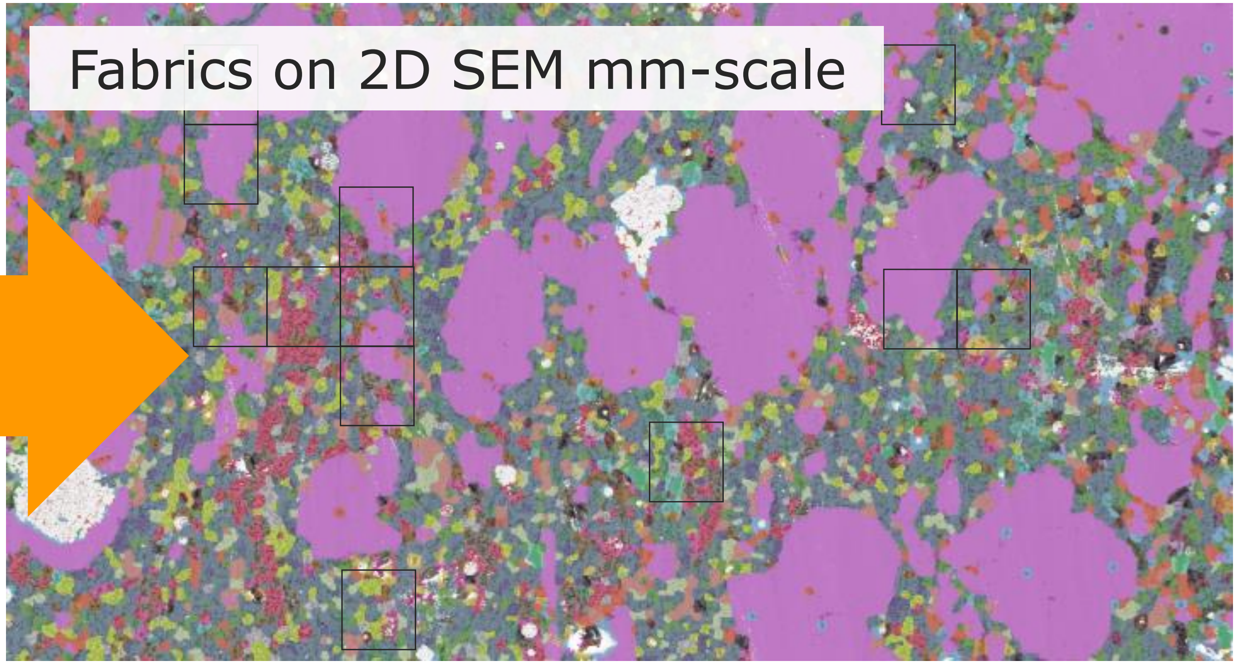
Rock Pore Associated with Organic (PAOM) Fraction

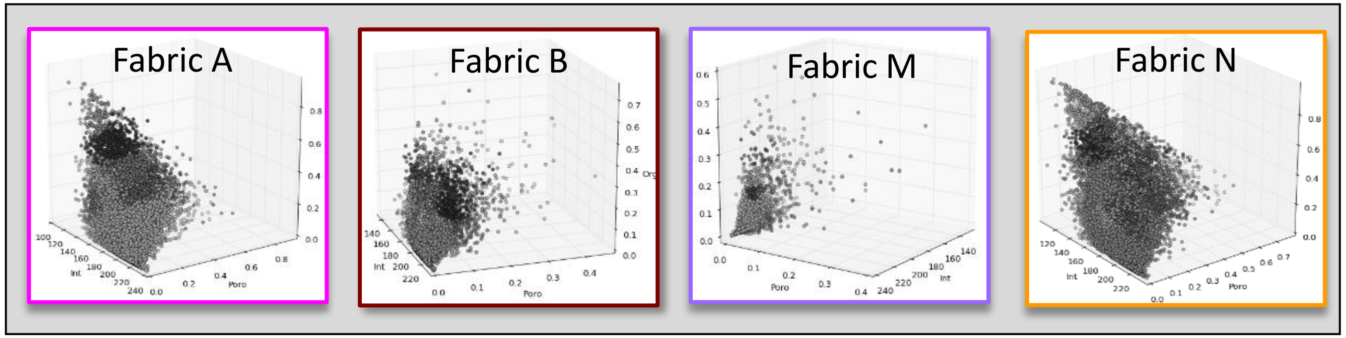








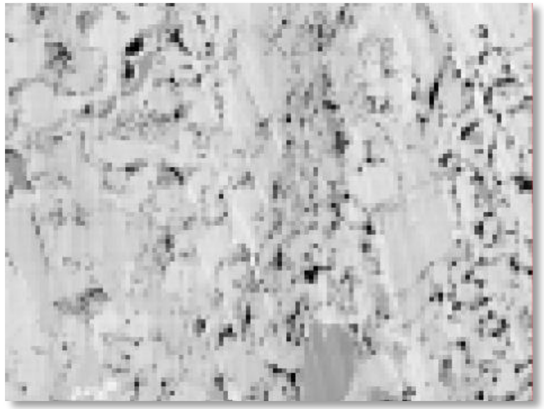




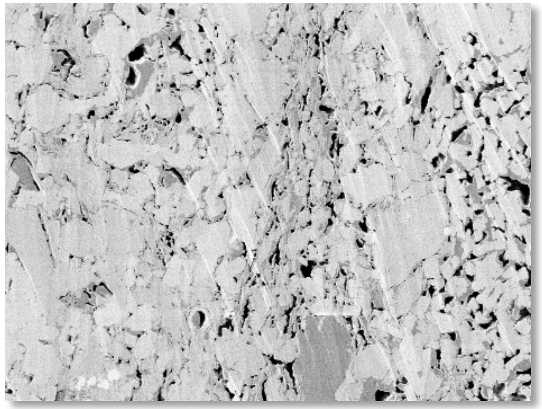
Multi-Scale Statistics

Multi-Scale Statistics

Low Resolution



High Resolution



$$I_{Low\ Res,fabric\ j} = \sum \left(\alpha_i I_{Material,i} + \varepsilon_i \right) + \varepsilon$$

Multi-Scale Statistics

$$I_{Low\ Res, fabric\ j} = \sum (\alpha_i I_{Material,i} + \varepsilon_i) + \varepsilon$$