[PS]A Multiscale Method for Characterizing Shales by Downscaling and Upscaling Statistically Sampled Datasets from Multiple Imaging Modalities*

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Abstract

Shale is well-known for its high degree of heterogeneity, requiring imaging across many orders of length scale in order to capture information spanning from lithological structure down to the grain and pore scale. Recent advances in 2D microscopy allow imaging of organic-hosted porosity in shales down to sub-nanometer resolution, but constructing large field-of-view images (by stitching many images into mosaics) at these resolutions, while possible, is not practical, as it would require weeks of imaging time for standard size 1-inch plug or petrographic thin section. A method for statistical sampling is therefore desirable to characterize the mudrock, utilizing instead an approach based on "downscaling" and "upscaling". In this abstract, we demonstrate a practical method for this approach - by using lower resolution plane and cross-polarized light micrograph images, and SEM backscatter and secondary electron images, we sub-divide the whole rock sample area into regions classified as different rock types or lithologies. Then, we statistically sample ("downscale") each lithotype at much higher resolutions sufficient to discriminate desired grain-scale mineralogy, organic content, and organic-hosted porosity. Properties of the grain and pore-scale resolved images such as pore-size distribution, pore connectivity in 2D, organic content, and mineralogy can then be used to extrapolate average properties within each lithotype ("upscaling"), which can then be linked to local depositional environment and micro-facies. Furthermore, within this process, it is beneficial to use multiple imaging modalities (polarized-light, electron, and energy dispersive X-ray microscopy) for determination of the above properties. We demonstrate the implementation of this technique on standard petrographic thin sections and end-trim of 1-inch core plugs, extracted from a standard 4-inch core. Upscaled data extracted via this method has the potential to be linked to core-level data and could be used to calculate or support calculations of such properties as net pay or original hydrocarbons-in-place.

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In this abstract, we demonstrate a practical method for this approach - by using lower resolution plane and cross-polarized light micrograph images, and SEM backscatter and secondary electron images, we sub-divide the whole rock sample area into regions classified as different rock types or lithologies. Then, we statistically sample ("downscale") each lithotype at much higher resolutions sufficient to discriminate desired grain-scale mineralogy, organic content, and organic-hosted porosity. Properties of the grain and pore-scale resolved images such as pore size distribution, pore connectivity in 2D, organic content, and mineralogy can then be used to extrapolate average properties within each lithotype ("upscaling"), which can then be linked to local depositional environment and microfacies. Furthermore, within this process, it is beneficial to use multiple imaging modalities (polarized-light, electron, and energy dispersive X-ray microscopy) for determination of the above properties.

Methods

Image Acquisition:

The light microscope images were collected on a ZEISS Axio Imager polarized light microscope at 10X under plane (PPL) and cross-polarized (XPL) light modes. Secondary (SE) and backscattered electron (BSE) images were collected using ZEISS Sigma field emission scanning electron microscope (FE-SEM). Quantitative mineralogy maps were collected using ZEISS Mineralogic Reservoir automated mineralogy system. High resolution (2.5 nm) backscattered electron images were collected using Energy selective Backscattered (EsB) detector installed on a ZEISS Crossbeam 540 FIB-SEM.

Image Segmentation:

Image segmentation for lithological classification was performed by texture based segmentation technique. The segmentation algorithm extracted texture information by using multiple texture-detecting digital filters. Texture based approach is essential as traditional histogram based segmentation methods fail at identifying rock types.
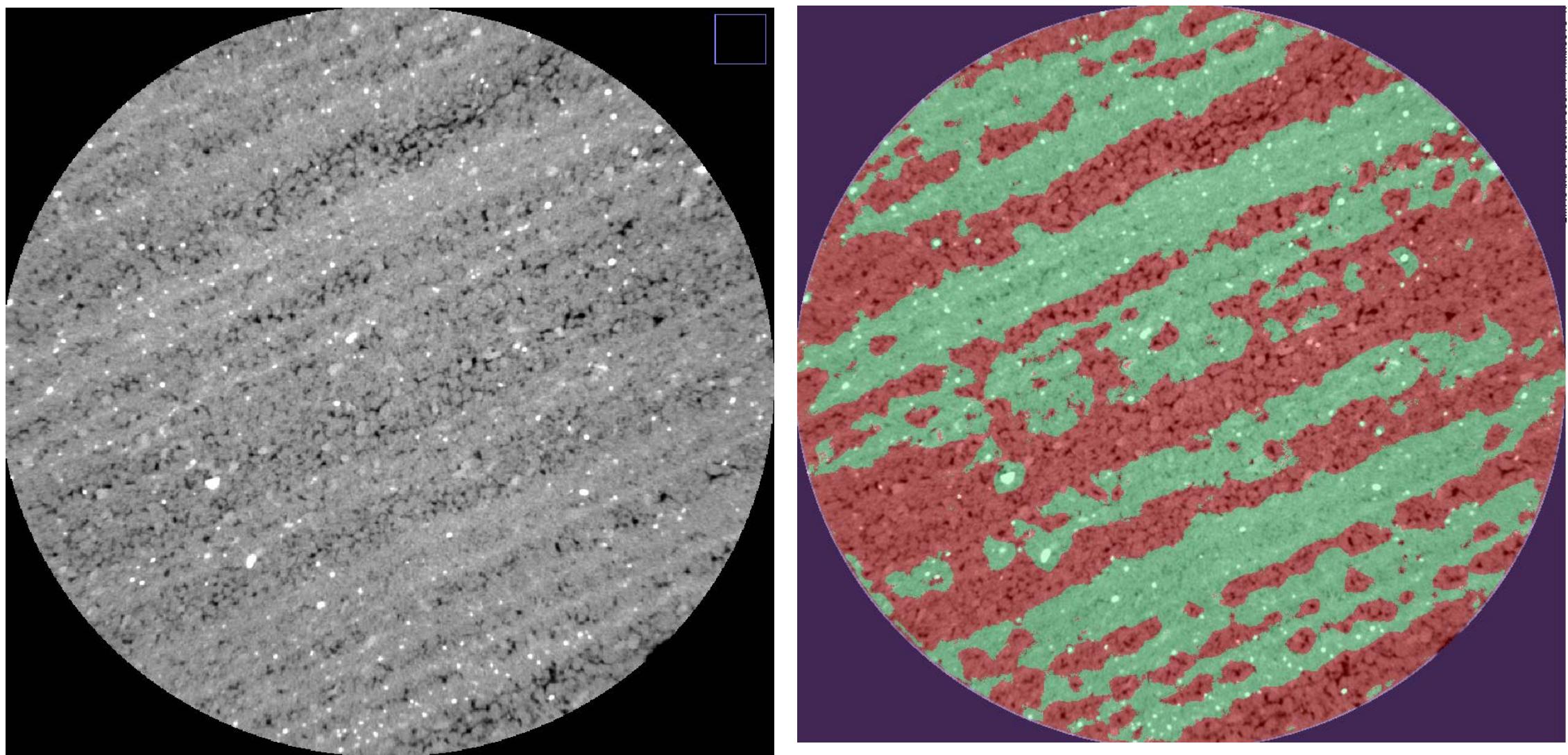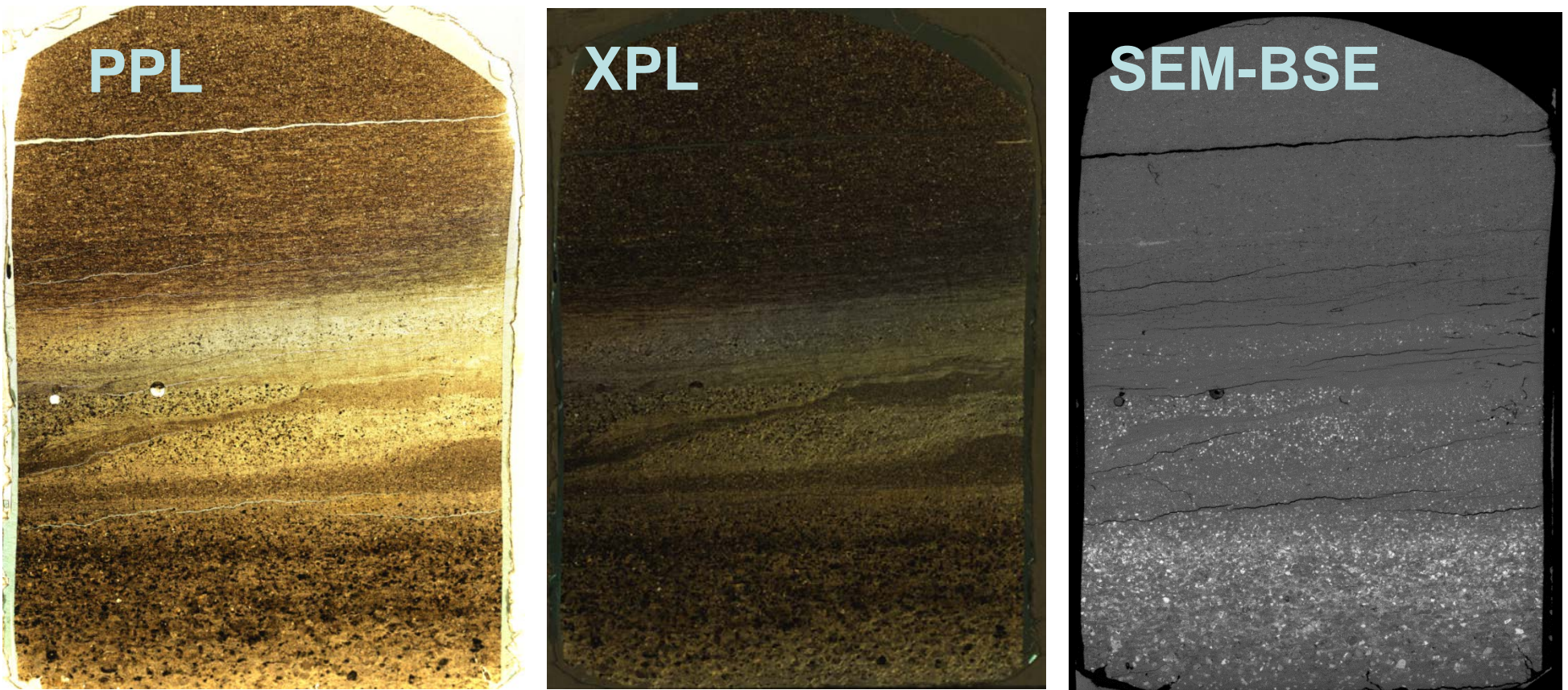
Left: X-ray microscope image collected using ZEISS Xradia Versa 520.

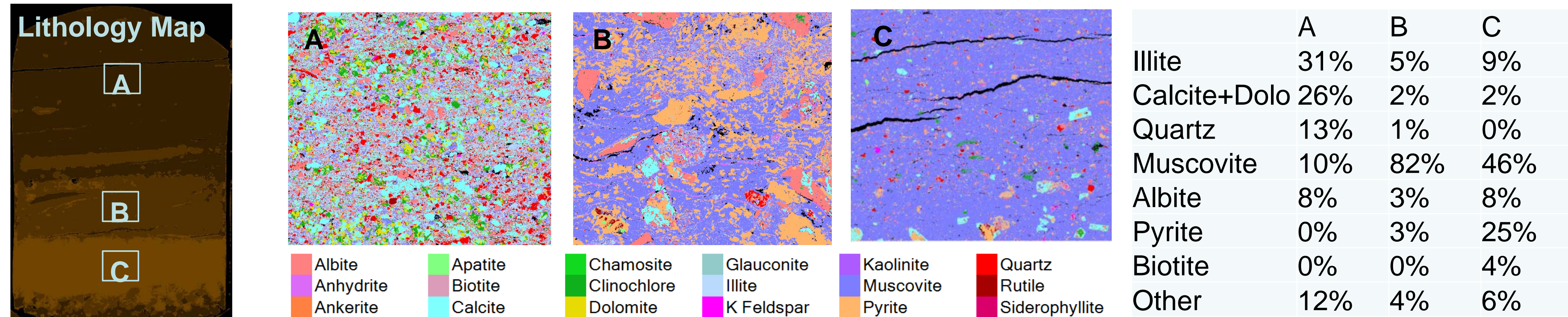**Right: Lithological layers identified by texture based segmentation technique.**

Results & Discussion

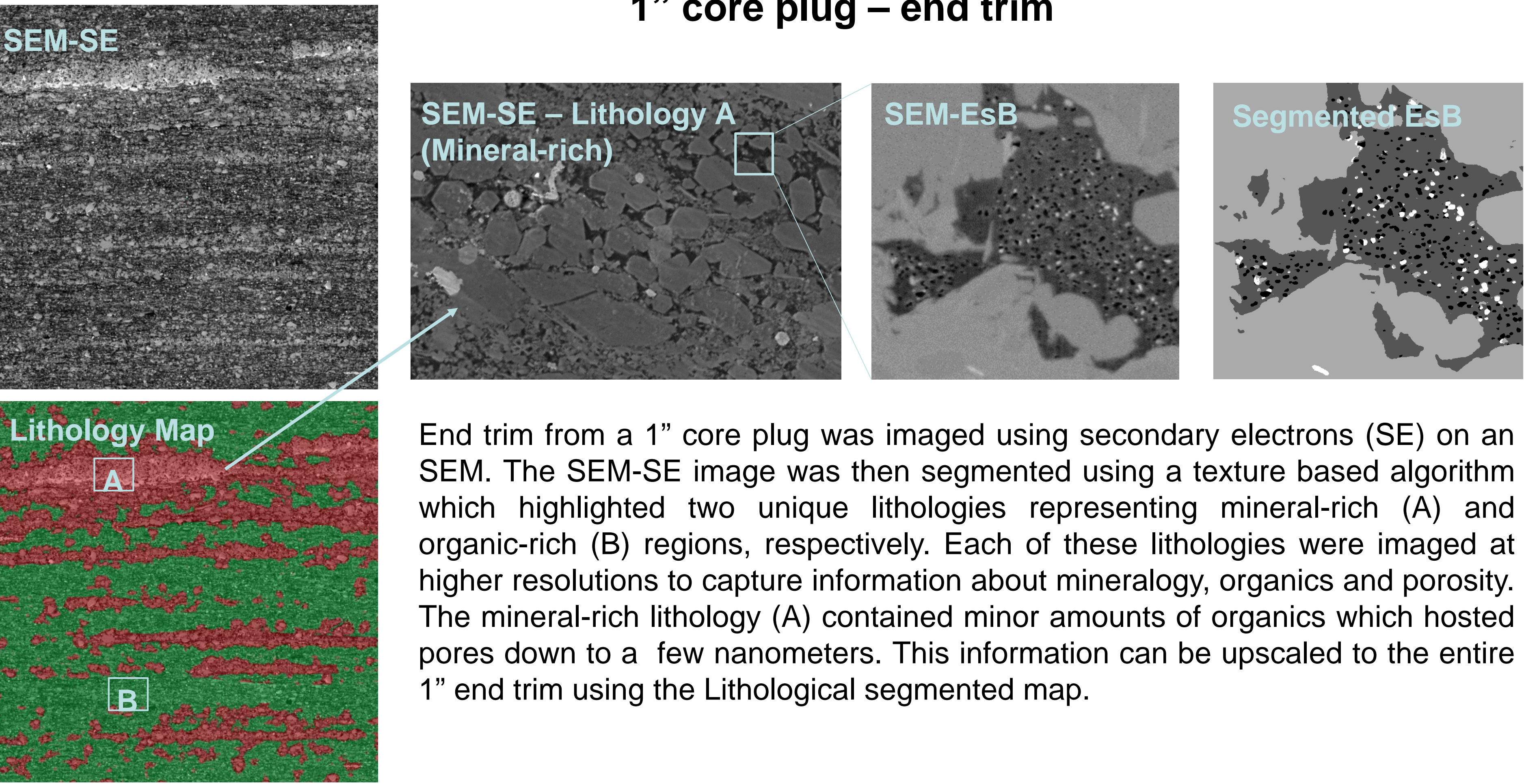**Petrographic thin section:**

PPL XPL SEM-BSE

Texture based segmentation algorithm was applied to PPL, XPL and SEM-BSE images to extract a Lithology Map that highlighted three unique lithologies (A, B and C) in the thin section.

Quantitative mineralogy maps were collected from each lithology. The mineralogy information can be upscaled to the entire thin section via the Lithology Map.

Lithology Map

A
B
C

	A	B	C
Illite	31%	5%	9%
Calcite+Dolo	26%	2%	2%
Quartz	13%	1%	0%
Muscovite	10%	82%	46%
Albite	8%	3%	8%
Pyrite	0%	3%	25%
Biotite	0%	0%	4%
Other	12%	4%	6%

Albite
Anhydrite
Ankerite
Apatite
Biotite
Calcite
Chamosite
Clinochlore
Dolomite
Glauconite
Illite
K Feldspar
Kaolinite
Muscovite
Pyrite
Quartz
Rutile
Siderophyllite

1" core plug – end trim

SEM-SE

SEM-SE – Lithology A (Mineral-rich) SEM-EsB Segmented EsB

Lithology Map

A
B

End trim from a 1" core plug was imaged using secondary electrons (SE) on an SEM. The SEM-SE image was then segmented using a texture based algorithm which highlighted two unique lithologies representing mineral-rich (A) and organic-rich (B) regions, respectively. Each of these lithologies were imaged at higher resolutions to capture information about mineralogy, organics and porosity. The mineral-rich lithology (A) contained minor amounts of organics which hosted pores down to a few nanometers. This information can be upscaled to the entire 1" end trim using the Lithological segmented map.

Conclusion

We demonstrated the implementation of lithological classification for downscaling and upscaling on standard petrographic thin section and end-trim of 1-inch core plug, extracted from a standard 4-inch core. Upscaled data extracted via this method has the potential to be linked to core-level data and could be used to calculate or support calculations of such properties as net pay or original hydrocarbons-in-place.