Nanoscale Porosity Analysis in Geological Materials

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Introduction

Current research puts growing effort into analyzing the porosity of various geological materials at nanometer-scale. This is based on diverse motivations ranging from evaluating clay as a host rock for radioactive waste disposal or investigating tight oil or gas reservoirs. Currently, the most accurate way of analyzing pore space morphology at these scales is Scanning Electron Microscopy (SEM) imaging on Broad Ion Beam (BIB)-milled cross sections as illustrated in Figure 1 (Desbois et al., 2009; Hemes et al., 2013; Houben et al., 2013; Klaver et al., 2012). Digital image processing technique is an automatic process for analyzing and visualizing the content involved in images, which is widely used in medical and biological applications but is still a challenge in geological materials like clays or shales. These fine-grained materials are typically heterogeneous in pore geometries, sizes and mineralogy. Porosity is difficult to segment from SEM images because of two effects. First, preparation artifact like curtaining hinders accurate segmentation. And second, pronounced edge effect at phase boundaries complicates derivation of segmentation algorithms. Reliable quantification of the data currently involves a significant amount of manual correction of the segmented images. As many of these fine-grained samples are mapped in the SEM, using different detectors (like Secondary Electron (SE), Backscatter Electron (BSE) and Energy Dispersive X-rays (EDX)), with sizes over 500 megapixels, and as the number of pores in a single map can be more than 400,000, it is obvious that the manual process is an immense workload. Therefore, an accurate, reliable, and automated pore segmentation required for analyzing BIB-SEM megapixel maps.

Materials and Methods

In our work we develop image segmentation algorithms to automate the process of porosity analysis based on SE, BSE and EDX-data. We use Matlab as programming environment. Our algorithms are based on standard image segmentation strategies adapted to the properties of geological materials and SEM images. We iteratively integrate imaging technique with software development in order to build a tool that allows automated analysis of various porous materials. Future integration to QT and python will allow user friendly handling of the data and graphs.

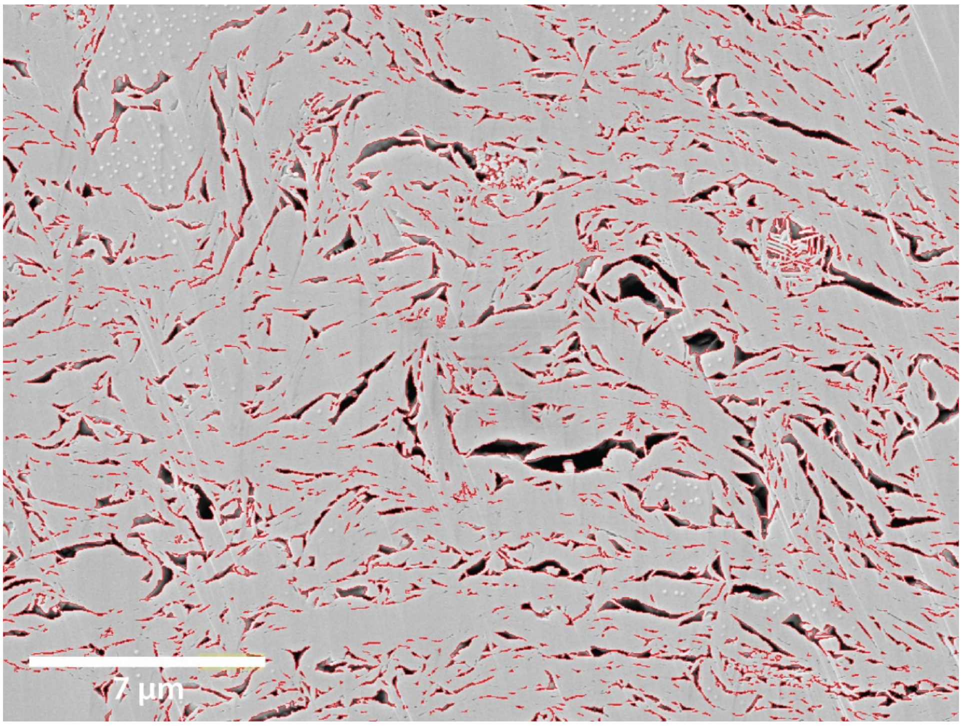

Figure 1. Secondary Electron mage showing porosity in clay. Over 5000 pores were segmented (red outline) in this field of view. The measured porosity is 11.95%

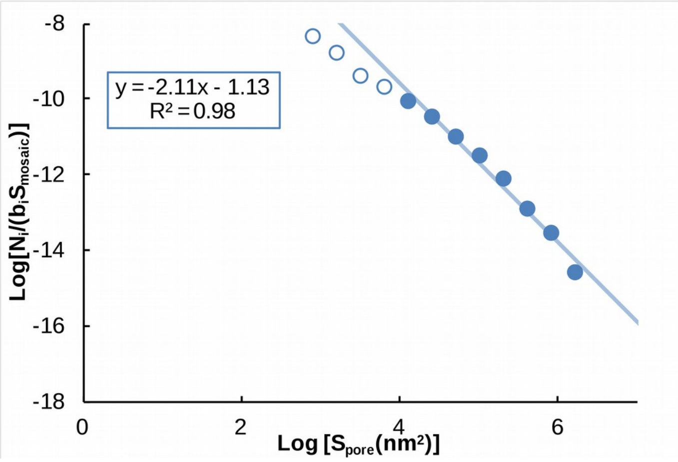

Figure 2. Graph showing power law distribution of porosity measured on SE-Image shown in Figure 1 and normalized by the measured image area. Segmentation is assumed to be valid for pores larger than 9 pixels which corresponds to ~10^4 nm^2 at the given image resolution.

Results and Discussion

Our workflow allows us the accurate segmentation of pores and determination of phase porosity. Based on the porosity segmentation, statistics and properties of the materials, such as pore size distribution and permeability, can be inferred. Our technique is not limited to geological applications as it can be also applied to the research of other porous materials such as ceramics, filters and membranes imaged with SEM or Optical Microscopy.

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