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Pore Super Segmentation in Opalinus Clay on Artificially Enhanced SEM Images with Voting Classification

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A material's porosity controls all of its physical properties. Hence, many studies have dealt with its exact determination. In researching potential host rocks for radioactive waste disposal, there is a particular interest in pore distribution and connectivity as this defines the rock's permeability and rheological behavior, e.g. in [Houben et al., 2013], [Hemes et al., 2011], [Klaver et al., 2012], and [Keller, 2021]. All these studies made use of specialized scanning electron microscopy (SEM). This analysis allows the evaluation of pores by size, location, orientation, and frequency by using a binary segmentation mask. The preparation of these masks is associated with some difficulties caused by the interpretation margins, non-uniform procedures, and, especially, by the resolution limit of the SEM. In addition, the overlap of gray values of grain and pores renders conventional methods such as pixel-thresholding unfeasible.

We present a method that deals with this problem in two stages. The first stage consists of an up-sampling technique of the SEM images. Here, the resolution of the images is artificially enhanced. In the second stage, this up-sampling is combined with an algorithm that computes a probability field using multiple learning classifiers (MLC). First, we trained and implemented an enhanced super-resolution generative adversarial network (ESRGAN) [Wang et al., 2018] for upsampling SEM images. The enhanced images show a much finer detail of pore edges, making even the smallest pores more apparent and detectable. In the second stage, nine different MLC's have been trained and examined for their segmentation results. Here, the characteristic segmentation properties of the trained MLC's are particularly noticeable. Their differences show that no single MLC alone can provide sufficient segmentation quality compared to manual interpretation. Hence, a voting classifier combines the individual MLC-masks into a probability field. This combination allows the derivation of confidence levels that reduce spurious pore segmentation and capture pore edges more organically and uniformly.

Finally, we have combined the voting classifier and the super-resolution to the so-called Super-Segmentation (SSM). The segmentation of the pores is now performed on the artificially enhanced SEM image. Eventually, the final binary segmentation mask is down-sampled to the resolution of the input image. Compared to other segmentation methods, SSM shows a clearer detection of the pore edges with enhanced quality even for the smallest pores. In a test case on Opalinus clay, we were able to detect pores that were undetected or insufficiently segmented. We discuss the result

and ongoing work to improve the reliability of MLCs with ESRGAN images with the goal to lower the truncation limit [Bonnet et al., 2001].