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Interactive comment on "Evaluating porosity estimates for sandstones based on X-ray micro-tomographic images" *by* Mathias Nehler et al.

Anonymous Referee #1

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The work focuses on determining the impact of micro-CT imaging and image processing on the porosity of rock samples. This topic remains a topic of interest, because improvement in X-ray technology extend the field-of-view / resolution operating window and improvements in image processing also provide potentially more robust and noise/artifact tolerant algorithms. The issue on the resolution limit has indeed been reported in the Leu et al. 2014 reference but potentially already earlier (see references in the Leu et al. 2014 paper). There are several follow-up studies, i.e. the one by C Soulaine, F Gjetvaj, C Garing, S Roman, A Russian, P Gouze ... Transport in porous media 113 (1), 227-243, 2016. There are also several more recent follow-up studies that build on the simulated Hg-air instrusion workflow introduced in the Leu et al. pa-

per and investigate the impact of resolution limit on porosity and permeability much more systematically, N Saxena, R Hofmann, F O. Alpak, J Dietderich, S Hunter, R J. Day-Stirrat, Effect of image segmentation & voxel size on micro-CT computed effective transport & elastic properties, Marine and Petroleum Geology, 2017. N Saxena, A Hows, R Hofmann, FO Alpak, J Freeman, S Hunter, M Appel, Imaging and computational considerations for image computed permeability: Operating envelope of Digital Rock Physics, Advances in Water Resources 116, 127-144, 2018.

First, It would be good to reference this work as it is very fundamental in nature and provides a conceptual limit to which extent the porosity in a certain rock is accessible by imaging at a given resolution. The work by Saxena et al. suggests that for porosities below 20% there are in many cases systematic differences between imaged and independently measured porosity, but it still depends on the actual pore size distribution. I would therefore encourage the authors to apply the workflow described in the Saxena papers and estimate for each situation which fraction of the porosity is not accessible because of the resolution limit. The second aspect that is important to mention is that porosity alone is perhaps not a unique enough parameter to determine the validity of a segmentation. It is much more important to consider porosity, and also permeability. The findings of Saxena et al. is that the resolution limit leads to a systematic under-prediction of porosity and/or overprediction of permeability, depending on how thresholds are chosen. But for an image below the resolution limit it is not possible to match both.

When it comes to segmentation algorithms, the focus is on absolute thresholding methods. It would be interesting to consider also other thresholding methods such as Watershed, C-means clustering, indicator Kriging, and perhaps also machine learning based methods like the trainable WEKA segmentation that is available in the OpenSource FIJI package. A recent overview is presented in S Berg, N Saxena, M Shaik, C Pradhan, Generation of ground truth images to validate micro-CT image-processing pipelines, The Leading Edge 37 (6), 412-420, 2018.

Concerning the imaging hardware, it would be important to determine the physical resolution of the system. I am not sure if the system is capable of achieving 2.5 micrometer physical resolution. The authors should verify that by using a JIMA test pattern for the relevant micro-CT settings.

Looking at Fig. 7, from my own experience, the NLM filter should perform better. I am not sure why the center of grains remains largely unfiltered. It could be a setting issue or input image quality issue. The 3D NLM filter available in GeoDICT or Avizo should perform better. Furthermore I would never consider using a median filter because of its impact on the sharpness on grain boundaries and the associated resolution limit issue. In the Leading Edge paper mentioned above, the best results are theoretically obtained without filtering, using a segmentation method that is robust against filtering.

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