

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

Anonymous Referee #3

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The work focuses on the effects of image resolution, segmentation and filtering methods on the evaluation of bulk porosity in different porous sandstones through CT imaging. I think the paper represents a good contribution to scientific progress, as it outlines the limitations of x-ray microtomography in evaluating bulk porosity. However, I think their data analysis and discussion could be improved substantially. In particular, the choice of the applied methods can be debated: there are many more robust segmentation algorithms and filtering methods that would perform better and will therefore have a different impact on the final porosity quantification. The choice of the authors for these methods have not been explained, hence their final conclusions are weak.

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Overall, the presentation of the data is well structured. Some figures could be improved (see specific comments). Some sentences can be structured better – they are hard to read for a non-expert in the XCT field (see specific comments).

I outlined below the major comments I have, and some specific comments later on.

Some general comments

1. First at all, the true spatial resolution (which is different from the voxel size) may depend on the sample type (e.g. grain size, composition), sample size, X-ray spot size and the precision of the alignment of the source, rotation axis and camera as well as the geometric magnification given by the ratio of distances between the source, sample and camera. Check Feser et al. (2008). In Line 9 -16, I think you should clarify better the difference between voxel size and true spatial resolution.

Diameter of the x-ray source, do you mean the x-ray spot size? Please be consistent in terminology.

2. The choice of the segmentation methods is a bit strange. If the aim of the paper was to assess the effects of different segmentation methods, you cannot base your findings only on global thresholding methods.

Line 34 – 35: Segmentation is the process to identify and separate phases, but it is not just based on threshold values. There are many algorithms (Indicator Kriging, C-means clustering, machine-learning algorithms such as the Trainable Weka, or watershed) that takes into account other parameters, in addition to the intensity. This misleads the reader, as the text here implies that segmentation is only possible though global thresholding, which is not true. In fact, paragraph in Line 5 should be tied up better to previous comment. In other words, why did you choose only global thresholding algorithms? Your choice is not explained.

3. I also disagree on the choice of the filtering methods. First at all, the median filter heavily smooths the edges of the objects, and the image becomes less sharp,

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impacting in the resolution. In addition, a kernel size of 3 is quite large – what does it mean that you applied the filter in 3 different successions? Is that referring to 3 different kernel sizes? And what about the impact of different kernel size or different neighbouring (6 vs 26)? The authors should consider that also these parameters may have an impact in the final quantification (and they usually do). In Figure 7, I would expect the NLM filter to perform better – what about the influence of the choice of parameters for the filter? Did the authors verify this?

There are many other denoising filters, that are definitely a better choice than the median filter, such as bilateral filter or Anisotropic Diffusion. In addition, the results of the filtering will significantly depend also on the choice of the parameters i.e. number of iterations.

4. Something minor to consider, but since you extrapolated subvolumes, would pores lying on the edges have an effect on the final quantifications? It would be interesting to repeat the analyses, by using “exclude edges” or “border kill” in Avizo. Also, I would add error bars in any quantification: since you are trying to assess the effect of different segmentation methods, when applying these methods your choice of the threshold is also subjected to error, therefore error bars are needed in order to estimate these errors. By using morphological operators such as erosion and dilation. See Fusseis et al (2012) for example.

Page 27, line 3 “We therefore conclude that filtering generally does not improve porosity determination” – Well, as mentioned in the points above, such a statement is odd considering that only 2 filters (and a mix of the 2) were chosen, while some more robust denoising filters are out there and should be included in this analysis for a more coherent discussion.

Specific comments:

1. Avoid sentences like “as one would” or “as one distinguishes” – always better to use a third person narrative style.

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2. Line 15: “Owing to its relevance”?

3. Page 3 line 3: reconstruction artifacts? I think it is artefacts.

4. You should explain what a voxel is, when introducing this term for the first time. A reader non-expert in the field would not know what a voxel is.

5. Page 4 line 18: what is sst? It took me a while to understand what it means, and please avoid using acronyms that i) are not scientific ii) you did not explain earlier on.

6. Line 19 page 4: how did you check for this? what if anisotropies were present at the microscale?

7. Is 6.6. mm² a representative area?

8. Assuming the samples are isotropic: what if they are not? In other words, it should have been tested.

9. Page 7 line 11-13: how did you account for errors derived from these measurements? Or are they extremely precise? Not an expert on the matter.

10. Page 8 line 21: “Each pixel in the detector has an edge length of 127 μm and a gray-value resolution of 14 bit resulting in a nominal system resolution of around 1 μm ” This sentence originally confused me – is it really necessary? I think it would be better to keep either nominal resolution or true spatial resolution, but not both as the reader may get confused.

11. Page 8 line 26: How is the resolution controlled by the magnification? Get equation (see Feser et al. 2008). Also, why is this mentioned here and not at the beginning, with the rest? Be consistent.

12. Page 9 line 20: I would put in brackets the real volume dimensions either in mm³ or um³.

13. Page 13, lines 21-25: this sentence is an interpretation and should be part of the

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discussions.

14. Page 14 I forgot what B, GBS and PS indicate. I would probably put the label next to them. Also, later in line 10 – you first describe the sandstones by using their relative content in porosity (highly porous sandstones) but then you call Group C, and I found this confusing: either you use the group names (since you just defined them) or the porosity content, just be consistent and do not mix between one definition and the other when listing them.

15. Line 13: the mean diameter falls below the resolution – does that mean that there is a lot of porosity missing from the CT analyses? And 211 designated pores – are these derived from SEM? As I am getting confused.

16. Figure 4, error bars: have these been defined in the text? I did not find it, maybe I missed it.

17. Figure 5: The eq. diameter here is calculated from SEM images, so it is a 2D calculation. At the same time, you mentioned the voxel size of the XCT and make a comparison between the voxel size and the mean pore diameter. However, the mean pore diameter is a 2D measurement and therefore this comparison in my opinion does not make much sense: it would be better to use the eq diameter derived from XCT images or make a comparison of the eq diameters derived from SEM and XCT. In that sense, porosity is not the only parameter to determine, but also pore throats, pore connectivity and permeability.

18. Table 2: P-wave velocity – existing measurements from where?? Or did you calculate them?

19. Figure 6: I think it should include the type of filter used, otherwise the reader has to go back and forth to table B1. A figure should be self-contained.

20. Figure 8: Where is GBS? In line 27 page 20 you refer to GBS in figure 8 I think.

21. Page 28 Lines 12 – 19: For very heterogeneous samples, scientists normally

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adopt a multi-scale imaging approach to determine realistic values of porosity and permeability, overcoming the issue of low resolution or not representative samples. Something to keep in mind for the discussion perhaps.

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