Dear editor, dear reviewers,

We thank the reviewers for the careful inspection of our manuscript and providing useful comments and recommendations that helped to improve our paper. We made effort to address all the reviewer's comments. Beside numerous corrections and further text, we added new Figures (Fig. 1E, F), a new table (Table 3), and another nine references. You find our answers in blue color. We highlighted the changes in the text by yellow background.

A. Bubeck (Referee)

Reviewers' Comments:

The submitted manuscript describes a study that aims to characterize pore size distributions, and the scaling of attributes, for two well-constrained types of sandstone using the following methods: 1) micro CT; 2) mercury intrusion porosimetry; 3) nuclear magnetic resonance; and 4) spectral induced polarization. Using curves of the cumulative volume fraction of pores and pore body radius, the methods are compared.

Generally speaking, the aims of the paper are clear, and data are well-presented. Improving our understanding of the nature of pore space in natural rocks is important to a broad range of study areas, including petrophysics and rock mechanics, for which a comparison of methodologies will be potentially very useful. It is my view, however, that the manuscript, in its present form, contributes little to our understanding of natural pore variability; resolution cut-offs for these techniques have been discussed previously. Many of the sections need rewriting to avoid overlap and repetition, and the motivation, and context for the study are unclear. For these reasons, it has been a challenge to review as thoroughly as I would like. Some simple restructuring and clarification could improve this but additional work is also necessary. For instance, the authors state early on that they provide a "multiple length scale characterization of pore geometry" - where is this data? A sentence in the conclusion section refers to "µ-CT enables a geometrical description of individual pore space. . .", but no data are presented. Providing additional geometric data would greatly improve the novelty of the work, and appeal to a broader readership. If the authors lack this data, I recommend that they remove references to geometry throughout. Furthermore, there is virtually no review of existing geological (or other) data derived using the techniques, nor their application, and a scattered discussion of the results towards the end of the manuscript. This needs work before it can be considered for publication.

We add a table (Table 3) with the geometric data derived from µ-CT in the Results.

The authors may decide that additional data, and/or background and discussion is beyond the scope of this work. If this is the case, then considering the broad readership of Solid Earth, they might consider submitting the work to a more subject-specific journal.

We selected “Solid Earth” because the pore space distribution and geometry is of interest for a broad readership of geoscientist: geologists, petrologists, geophysicists, petrophysicists. A comparison of different methods used in this field should be a motivation not only to apply the traditional standard methods. SIP is a novel method in this field. It is our aim to check the potential of this method in pore size characterization.

As a final note, the manuscript should be given thorough proof-read from a native English speaker; language, grammar, and sentence structure require work before I think it is ready to publish. I have not made specific edits related to these because they are numerous. Below, I have provided section-specific comments for the authors.

I hope the authors find them helpful.

We thank for the critical and helpful remarks. We tried to address the remarks and added additional information as recommended by the reviewer.

MS Specific Comments

0. Abstract The abstract reads fine and, with some minor edits, reflects the main findings of the manuscript.

Line(s) Comment 39 ". . .pore space geometry. . ." Global edit: you do not discuss pore geometry in this work. Please remove reference to it unless you have additional data to add.

We add the text defining the geometry here.

1. Introduction This section needs some restructuring, and expansion. For submission to Solid Earth, the work should mention the existing applications of these methods (geological, and others). The authors could consider including a background section to present existing uses of each method, their limitations, and how this data is used. This would improve the framing of the work, and broaden its appeal to different readers.

We add some references of the applications of these methods.

These are some questions I have from this section: a. What are your motives for the study? b. Who are you targeting with this work? Petrophysicists? Is Solid Earth the best place to present this? Porosity, and its effect on fluid flow and the mechanical behaviour of porous rocks is important to a range of study areas, and the subject of extensive study. A (brief) review of some the existing literature would help - e.g. recent uses of x-ray CT to analyse pore volume/geometry/distribution and fluid flow through porous media.

Line(s)

52-57 This isn't much of an introduction for the study.

We add the text defining the geometry mentioned in this paper.

63-67 I think you could move this to your discussion section and expand on how results from these studies compare to your own.

68-75 This section isn't very clear. You mention 3 separate published NMR studies but no others? It is not immediately clear what the relevance of these studies are to your own motivation, or results. You should add some background for the other methods too. Speaking for micro CT, there are several studies that analyse rock pores that the authors should take a look at, including: Lindquist et al., 2000; Ketcham, 2005; Nakashima and Kamiya, 2007; Takahashi el al., 2016; Schmitt et al., 2016; Saenger et al., 2016; Bubeck et al., 2017; Zhao et al., 2017 (this last one should be particularly helpful in helping you structure and present your work).

We reconstructed this section.

76-83 This section is partly repeated. Read through your introduction and keep it concise.

Correction done.

77 Either: add a section that deals with pore geometry specifically, and include additional figures/data, or remove this.

Correction done.

80 ". . .distributions are connected to each other. . ." This is unclear.

Correction done.

2. Methodology

This section is very long and it looks like a mixture of background and methodology, which could be split up. Keep your methodology simple: what did you do, and to what?

A number of questions need to be addressed in this section to improve the clarity of your results. a. How many samples did you use in total? b. How many samples did you run for each test? This needs explanation to demonstrate that the results are repeatable. You could add this data to table 1. You should also explain what size samples need to be. c. Does sample size effect the results for any of the methods? It should certainly be considered in micro CT. d. Did you characterize grain size? What role will this play?

We reconstruct this section and add the sample information in Samples and methods section.

Line(s)

91-99 This is background

Correction done.

99 The use of fractals (in geology alone) stretches considerably beyond these references. If you are presenting data on pore scaling relationships, expand this and move to a background section.

We change the term ‘geometric objects’ to ‘pores in sandstones and carbonates’.

100-102 Good. You should move your sample descriptions into this section.

Correction done.

103-108 Tell me what you’re doing/using before you tell me the limitations of it.

Correction done.

109-110 How have you performed this analysis, what were the results, and why is it best? More information and figures to explain this process are needed. Why compare with 2D SEM images?

We used a standard analysis of the µ-CT data. A comparison between 2D SEM and a 2D slice of the CT image is shown in Figure 1. We add a Figure showing 3D images of pore network resulting from µ-CT.

113 ". . . each individual pore. . ." Where are your data for individual pores? You could present data on the proportion of pore body radii (how variable are they within samples? How

do your different sandstone types compare?), their geometry and preferred orientation (if present).

We add a new Table 3 summarizing the geometric information resulting from µ-CT. The data of individual pores contains over 10000 data points so the table is not shown in the paper.

114 Do you have references for this technique?

Correction done.

119 You're using MIP specifically for pore throat radius? Be clear about what data each method is providing!

131-132 Try to explain this more clearly.

The detailed explanation can be found in the reference. You can imagine the big pore as a room with a door (throat), and the MIP data records the size of the door instead of the room.

139-145 Background.

Correction done.

142 "a capillary model with cylindrical pores, of uniform radius. . ." - How useful is this? Is it reasonable to assume a linear relationship for natural pores, which may be neither cylindrical, nor uniform? Kleinberg, 1996 applies it to "slit-like pores". You should provide some geometric description of your pore space to support the use of this model. At the VERY least, explain how your results could vary. You could leave this as is here, but add a section to your discussion covering possible limitations of the method and expand on this there.

The reviewer addresses an interesting issue. The surface to volume ratio is not very sensitive to the shape of the pores. As mentioned in the text, a cylindrical pore results in a surface to volume ratio of 2/r and a spherical pore in 3/r. The resulting difference (factor 1.5) can be ignored when looking at a logarithmic scale. The word "uniform" is deleted. A cylindrical pore has a constant (uniform) radius per definition. The geometric descriptors are compiled in Table 3.

150-151 "The range of resolved pore radii depends on the used value of surface reflexivity." – You need to explain what value you have chosen, and why? If similar assumptions apply to the use of a single value here, address it in the discussion also.

The correct choice of surface relaxivity is not a simple issue. We have demonstrated in chapter 4 a procedure to determine ρ from a comparison of µCT and NMR. This procedure demonstrates a joint use of different methods improves the reliability of the derived parameters. Applying this procedure, we got different surface relaxivities for the Bentheimer (ρ = 54 µm/s) and Röttbacher sandstone (ρ = 237 µm/s).

175 Quantify the "restricted range"

Correction done.

182 Did you have any repeatability issues? Do you think two sufficient?

In most cases, two measurements are sufficient for checking the repeatability of the acquired complex conductivity spectra. If the two measured spectra show remarkable differences, additional measurements are performed until no temporal changes are performed.

187-224 This section is a mixture of background, discussion and results, with some repetition. Read through carefully and move elsewhere where appropriate.

Correction done.

3. Sample material This section is a mixture of methodology and results. Does it need to be a separate section? I think it would be helpful to have this information earlier. When you're describing the methods, it will help to know what they are related to. The section could also be much shorter. I recommend you edit the information into your methodology, explaining the number of samples used and their sample sizes

Correction done.

Line(s)

227-228 Cut this. Unnecessary.

Correction done.

244-245 Remove 245-247 Background

We think that this additional information might be useful for the reader familiar with different types of sandstones.

251-262 This is your data? It needs to be in the results section.

Correction done.

4. Results The description of the graphs in this section is rather vague and unhelpful - you refer to "differences" between curves but don't describe or quantify these. Equally, stating that something is "larger" or "smaller" is also unhelpful. Quantify your observations!

I suggest changing the section titles here to refer to the parameters measured, i.e. pore volume fraction, pore throat radius, and scaling. Describe the results of these for each rock sample. This would be easier to follow than describing each rock; it is the technique that should be the focus of this section.

Correction done.

Your fractal data is currently lost in your discussion section. Move it into your results and consider a table that compares the dimensions obtained.

The reviewer finds all the derived parameters of our study in Table 1 including the fractal dimensions for the two samples.

Line(s)

282 ". . .wide range of pore radii. . ." State the range measured for each method, with

upper and lower limits clearly defined.

Correction done.

289 Explain this more clearly.

We describe in line 289 the observation in Figure 2 that the µ-CT curve is shifted to larger pore radii in comparison with MIP.

5. Discussion

This section is a confusing mixture of results and discussion. You should read through it carefully and remove results to earlier sections.

After reading the discussion, I have a number of questions that can be addressed by restructuring and expanding the discussion. a. What are the implications for the pore size distributions you have obtained? There is no real discussion of the importance of pore size distributions, or their use, in this work. . . b. What effect do you think your results have for studies of the mechanical behaviour and fluid flow properties of your samples? c. How do

your results compare to existing characterisations of these samples - are you offering an improved resolution? How important is it for samples like this? d. How strongly dependent are your resolutions on rock type? How would they vary for other rock types: Limestones/volcanic rocks for example? e. Are the approaches described suitable for a range of rock types/sample sizes/porosities? I would like to see this section discuss the implications of the results more broadly. f. Which of the techniques is best? Which one provides the most, useful, information -and for whom? g. What are the limitations of your findings?

We reconstruct the Discussion section.

A summary table of the data provided by each method, and resolution would be helpful to readers.

We guess that the reviewer has overlooked Table 1, which is summarizing the parameters derived for the two samples of our study.

Also include a limitations section and use this as a basis to explain which methods should be used for certain applications, and how cautious researchers should we be when interpreting the results.

6. Conclusions A lot of the material in this section could be moved into the discussion.

Add a sentence summarising the importance of the result of this study.

Line(s) 399-407 These are (some of) your conclusions. The rest can be moved.

7. Figures/Tables

Suggested new figures: a. Demonstrate the 3D pore network would be helpful when describing your samples (e.g. Figure 3 in Zhao et al., 2017)

b. Segmentation/MIS

We added 3D images (Figure 1 E, F) showing the pore network for the two samples.

c.Plot your body radii against cumulative frequency.

We do not see the purpose of such a plot. We prefer to plot the cumulative volume as a function of pore radii as explained in the text, because this graph in a log-log-plot enables the determination of the fractal dimension.

Figure 1 No changes suggested.

Figure 2 Label the two values (0.238 and 0.184) in the caption.

Correction done.

Figure 3 No changes suggested.

Figure 4 Label each part as A and B; describe them separately in the caption.

The curves of the two samples are displayed with different symbols and can be easily differentiated.

Figure 5 No changes suggested.

Figure 6 Label values as for figure 2.

Correction done.

Figure 7 No changes suggested.

Table 1 Where does your permeability data come from? I recommend you convert these values to m2.

The gas permeability has been measured and Klinkenberg correction has been applied. The unit mD has been converted into m^2.

Table 2 No changes suggested.