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Interactive comment on "Digital Carbonate Rock Physics" *by* Erik H. Saenger et al.

Anonymous Referee #2

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The approach of using X-ray micro-CT in carbonates to obtain P- and V-waves is relative new and the idea of selecting distinct threshold values for the frontier between pores and solid matrix is interesting and relevant for the 3D image analysis, presenting a potential addition to the literature dealing with carbonate and digital rock physics (DRP). However, the paper is somewhat written in a confuse way and should be clarified and sharpened throughout the text to improve the understandability of the results. The authors should concentrate more in explaining and discussing their results, instead a big part of the paper deals with the results of other authors with named Tables/Figures (See e.g.: Page 3, line 15; Page 7, line 4; Page 13, line 5) which is inappropriate since results from the literature that the authors refer to should be included in the text of somehow in the paper' structure. Even though it is important, there was a lack of connection between the literature and the authors' own results: what was new from the author's paper compared with the previous literature? The discussion and conclusions were not very clear; for both sections there is a need of pointing out and correlating

the values and results from the tables and figures in the text. In addition, the theory of P- and S-wave velocities applied to the carbonate samples characterization should be elucidated. I suggest a previous definition, its importance related to DRP and the analyzed samples; provide a more detailed discussion between the experimental results and its practical applications. Several comments have been incorporated along the text (see below). Please take them into account (but not limited to) as much as possible.

The title is too general; The Authors should rename the work to better show the focus of their studies.

Abstract: The abstract could be less general also some results (values) should be listed. Page 1, line 15: Please list numbers to the resolutions; line 17: Mention briefly the properties complemented with nano-indentation; line 20: By "intermediate phases" do you mean "intermediate threshold values for distinct phases"? Lines 21-22: This structure is very confusing. To clarify I suggest the authors giving names to the technique/method used in the laboratory to measure porosity, to the predicted effective properties and to the technique used to acquire the experimental data; line 23: Specify that "some sub-samples" actually refers to the distinct smaller regions of interest (ROIs) selected from the acquired CT-datasets. I would also replace "in our case" to "analyzed rocks".

Text: Page 2, lines 7-9: When performing 3D images analysis a helpful tool to investigate and verify the representative elementary volume (REV) of subsamples is using autocorrelation function. Did the authors investigate REV of their samples somehow? The related literature can help: Haussener, S.; Coray, P.; Lipi′nski, W.; Wyss, P.; Steinfeld, A. Tomography-based heat and mass transfer characterization of reticulate porous ceramics for high-temperature processing. ASME J. Heat Transf. 2010, 132, 023305:1–023305:9. Petrasch, J.; Wyss, P.; Stämpfli, R.; Steinfeld, A. Tomography-based multiscale analyses of the 3D geometrical morphology of reticulated porous ceramics. J. Am. Ceram. Soc. 2008, 91, 2659–2665. Haussener , S.; Steinfeld, A. Effective Heat and Mass Transport Properties of Anisotropic Porous Ceria for Solar Ther-

mochemical Fuel Generation. Materials 2012, 5, 192–209. Costanza-Robinson, M.S.; Estabrook, B.D.; Fouhey, D.F. Resentative elementary volume estimation for porosity, moisture saturation, and air-water interfacial areas in unsaturated porous media: Data quality implications. Water Resources Research, 47, WO7513:1–WO7513:12. Bear, J. Dynamics of Fluids in Porous Media, General Publishing Company LTD, 1972. pp. 19–21.

Page 2, lines 11-13: In which type of material/rock? This statement can be invalid e.g., when analyzing other rock types such as shale; line 16: "3D rock models"? Maybe, "3D rock pore networks". Line 19: It is not the porosity which is smaller, but the pore sizes; lines 20-22: Once more authors draw a statement which is in fact strongly depending on the material/rock type and acquired voxel resolution. Please add rock type and resolution range to correct sentence; line 28: rephrase sentence.

Page 3, line 2: Take out "as well"; lines 3-6: How did the authors managed to improve "digital rock images themselves and/or the computational workflow"? Describe it succinctly relating e.g., image enhancement with image acquisition parameters, voxel resolutions, pre- and post-processing; line 4: Correct the verb form; line 6: name the "suggested techniques"; line 7: Complementary in which aspects? Authors should use this structure to point out in more details the importance of their work and in which aspects it is novel and relevant compared with the former cited studies.

Pages 3-4, lines 26-7 and Tabs. 1 and 2: Remember using S.I. standard units and note that the numerical value precedes unit and a space is always used (except for degree, minute, and second for plane angle) to separate them.

Subtitles are too short and should be improved making a least description of each subsection.

Page 4, line 14: "(RMS values)" should be moved to right after "1.4 μm".

Page 5, lines 12-16: Authors mentioned Poisson's ratio but do not say which values

they used for their calculation? Fig. 1 is under explained, e.g., the blue and green areas mentioned in the caption should be clarified in the text; Explain also which is the relation/implication between the "blue and green" areas and the nano-indentation results. Clarify the real mean/relevance of Fig. 1 to the paper context as well.

Page 6, line 1: Inform the source-to-sample distances in Table 3 and change "pixel size" to "voxel size" adding the cubic unit to the values as well; line9: "illuminate"? Line 12: I suggest the authors take out Fig. 2 and only present this sequence in the text itself, since this workflow is relatively simple and brings no novel information to the paper; line 13: Give the voxel size of selected ROI. Fig. 4: Authors should describe the dark green areas, which are overlapping volumes between neighbors subsample ROIs, to improve understanding of their procedure; line 18: Keep a standard on typing: "subvolumes" or "sub-volumes", "subsamples" or "sub-samples"; Lines 20-22: "appropriate dimensions and kernel window sizes" which were?

Page 7, line 7: Were the same Carb-A and Carb-B samples investigated by Vialle et al., 2013? In positive case, I suggest the authors to add the values of Hg porosity and compare it succinctly to the He porosity (shown in Table 1) and distinct CT porosities obtained from the thresholds levels of micritic phases. This will give an idea of the optimal threshold value which is surely related to the effective rock properties moreover discussed in the work. Line 14-15: give the used values for pressure bound condition and dynamic viscosity of fluid; line 19: what does the form "RSG" stand for? Note that Fig. 6 was not commented in the manuscript text. If Fig. 6 isn't that relevant to the paper' findings it should otherwise be taken out.

Page 8, line 6: What do you mean by "most relevant subsamples"? Give the criteria to judge a subsample relevant; also do the authors mean by "numerical investigation" in this structure the P-and S-waves velocities? Please clarify! Because if one looks to the numerical investigation of permeability (Figs. 7 and 9) it is possible to see that simulations were performed in all 8 subsamples, while P-and S-waves velocity simulations are given only for one subsample (give the subsample names in the legend) of each

carbonate (Figs. 8 and 10). In Fig 7, add “simulated” after “Intrinsic permeability” and in the graphic axis (in Fig. 9 as well). Comparing the results of permeability simulations for the high resolution (Fig. 7) and the low ones (Fig. 9) one can see that only the minimum and maximum threshold values were depicted in Fig. 7. Please elucidate the reasons for that. Lines 11-18: Authors made a good observation and should justify this result better. Another interesting find when comparing Figs. 7 and 9 is the variation on the permeability results between subsamples: for the low resolution results less variation in the permeability is observed compared to the higher resolution, indicating less anisotropy of the subsamples and more material representativity. It is an important find in your study, you have it in numbers and you should highlight it! Observe as well how the subsamples of Carb-B (high resolution) showed to be heterogeneous; even though as the authors describe “it shows a much lower variation between the extreme values”, the subsamples have extreme variation in the permeability values compared with subsamples of Carb-A. Which would be the probable causes for these results? Line 18: This statement is half wrong! Line 20: Here the “micritic phases” term is given without a clear explanation that they actually are the distinct phases identified from the threshold’ classes of 3D images (as described in section 3.2). Please clarify it also linking it to the Fig. 5. The same is happening in section 4.2.1 when a new term “six possible domains” is introduced.

Page 9, line 12: In fact the threshold values are being varied what implies in the porosity change! Lines 18-19: Make sure to inform that these results are shown in Fig. 11; lines 22-23: Rephrase structure; lines 25-26: Rephrase the position of “(Figure 10)” in the structure.

Page 10, lines 1-4: I disagree that only Carb-B showed slightly difference, which can also be seen in the P-wave results of Carb-A, on which data “a blue dashed-dotted line” should be fitted as well. IMPORTANT: Note that if P-waves are represented with the blue color in Figs 8 and 10, captions must be corrected. Lines 13-16: The performed procedure and described results are very interesting for a better discussion; lines 21-

23: Make a link to it commenting the finds from Barb-B (Fig.7) and discussing in a practical manner how the present work overcomes this problem.

Page 11: Section 5.1: Although the idea of correlating estimated elastic properties of carbonates based on distinct micritic phases identified from the threshold’ levels in micro-XCRT images, with experimental nano-indentation experiments sounds very attractive, the authors failed in their expectations described in the lines 22-24. For a rock/material having a defined amount of pores and solid matrix, one can expect an image threshold with at least two peaks: one in the darker gray levels regions (related to the pores) and another in the brighter regions (linked to the matrix); however If the analyzed material has also a certain amount of heavy phases (e.g. iron) then another additional peak in the threshold can be observed. Whereas (as the authors described very well) it is difficult to see the moduli peaks of pores in the nano-indentation experiment results, naturally because the values are very low. The relation from the micro-XRCT images and nano-indentation experiments using the number of threshold peaks seems somehow inappropriate.

Page 12, lines 5-8: Include figures numbers (low and/or high resolutions) of your work to improve reading and understanding; line 16: nane the technique used to the measured porosity or add “as shown in Table 1”. In line 18: specify “full sample”. Lines 22-24: Authors should be careful and add in this statement, that this observation is for their specific case (Carb-A and Carb-B) within the investigated resolutions which is based on the single image scales. Nowadays the use of multi-scale approaches to investigate porosity and DRP of heterogeneous rocks such as carbonates became widely common and has proving to be reliable.

Page 13, lines 2-3: name the tables/and figures from were readers can see these results; line 9: change to “experimental measurement”. Line 12: name the porous materials; lines 15-16: How “statistically significant” (also given the Summary) samples should be? Try to base it on your results with the proposed approach using multi micritic phases and subsamples (ROIs).

Page 14, section 5.5: the statement that “any significant anisotropy for permeability” was found in the analyzed samples is in disagreement with some of the paper’ results (see e.g. Fig. 7). Elucidate the anisotropy changing from the higher to the lower resolutions, more evident for Carb-B than Carb-A.

Concerning to the Summary: Summary is in general written in a confuse way making it hard to follow the author’s thoughts. The summary should be rewritten in a more focused and brief way. Again, the authors provide their conclusions without backing them up with the quantified values that they base their assumptions on, making the work appear somewhat subjective. They tend to loose themselves in generalizations such as “the porosity of the rock samples is the most relevant parameter”; certainly the authors do not mean that for any purpose in the world including rocks porosity is the most relevant parameter, as an example for structures that need to be sharpened and detailed.

Several references are missing, i.a.: Page 2, lines: 10-11, 14-15, 15-18, 22-24; Page 4, line 22; Page 5, lines 3, 7; Page 6, line 8 (reference the model used in the reconstruction); Page 6, line 20; Page 7, lines 7, 10; Page 13, line 27.

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