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Solid Earth
Discussions

Interactive comment on "Benchmark study using a multi-scale, multi-methodological approach for the petrophysical characterization of reservoir sandstones" *by* Peleg Haruzi et al.

Anonymous Referee #1

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1 General comments

I read the paper of "Benchmark study using a multi-scale, multi-methodological approach for the petrophysical characterization of reservoir sandstones" with great interest. It deals with so called "digital petrophysics", a characterization of petrophysical properties of rocks, essentially but not limited to porosity and permeability, by evaluation of 3D microCT scans through different statistical and analytical techniques mutuated from image analysis. In this particular study, 3 sandstone samples from different layers of the Hatira formation in northern Israel were characterised.

The samples were subjected to a good array of analyses, from more standard such as gas and mercure porosimetry, to more advanced ones such as indeed 3D imaging by microtomographic scanning and the subsequent analysis and flow modelling, in the ultimate quest to obtain in silico reliable "macroscopic" (Darcy scale) description from the pore space imaging. The authors detail their characterization of the spatial variability and variographical analysis of the 3 microCT samples in order to obtain the minimum size of REV, which they claimed being only possible for two of the three samples. Once the REV size determined, Navier-Stokes simulations on the discretized pore space were run to compute the full apparent permeability tensor of the samples. The discussion puts their findings in perspective with the current state of knowledge in this matter, notably enumerating possible sources of errors.

Up to a few imprecisions in the description of the employed geostatistical instruments, the paper has a good scientific quality and practical relevance, and it is written in good english. Even though no groundbreaking results or new methods are introduced, it is the combined use of different methods the strength of this paper, which I believe merits publication in SE after some improvements.

Before diving into the specific and technical comments, a remark: since the paper claims to be a "Benchmark study", I strongly advocate to make at least the segmented 3D scans available in one of the many available public data repositories.

2 Specific comments

1. Please use "semivariogram" instead of "variogram", or state in the text that you are using "variogram" to intend "semivariogram", as I will do from now on in this review.
2. Is the support used to compute the experimental variograms the whole image plane orthogonal to the computed direction? It is not completely clear to me

at the moment, I find the Methods description misleading in this regard. If it's the case, I strongly advice to use for variography at least squares and not the full slices, and even better yet would be to do a full 3D variography, doing cubic supports as you did in the "classical" REV analysis of figure B1. Though, this is much more computationally intensive and may require ad-hoc coding. This may have a potentially large effect on the results, depending on the chosen "box side", especially for the sample S2, and if done properly, also actually hint at the true principal axes of anisotropy for the samples, which may not be aligned with their sides.

3. Fig 9-11: if you are showing the fitted variograms, based upon which you define the apparent ranges, I believe you should also state which variogram model was fitted. From the legend I may assume it's an exponential model but or spherical or something else, and the "expo. fit". If it's the case, then you need to specify if the reported "range" is the actual coefficient in the exponential model or the "practical range" of the asymptotic function.

4. All three samples represents exemplary cases for zonal anisotropy, where the sills of the variograms are not constant following different directions. This reinforce my suggestion of making the samples available to the public.

5. It is to me however striking - and this may hint to a too large support definition, cfr comment 2., or else to a graphical imprecision - that no experimental variogram displays any nugget effect. This could mean that the variable has been excessively regularised. Please state in the text how the lags for the calculation of the experimental variagrams were chosen, and if the computed pairs at each lag bin are comparable.

6. Fig 11. Regarding the variograms of sample S2, they are clearly linear, especially the xy plane, which is a clear sign of non-stationarity, as also clear from the strong trend in subfigure (c). However you also correctly recognised the "external drift"

represented by the clay content. This is possibly a textbook example of external drift, which makes the de-trending of porosity worth. My point here is, that the fact that the sample is clearly strongly anisotropic and non-stationary does not mean that it is not possible to extract a REV from it, at least for the two other directions, but with some manipulation, also in the xy plane. Moreover, a full 3D variography (if my 2. comment is valid) may give different insights and results.

7. No histogram of apparent image porosity is displayed, neither from the slices used for the variographic REV nor from the subsets of figure B1, although from that figure we get an idea of the "density" (however there is sampling involved here, I assume). Is it possible that the "cube" porosity - at a given cube size - is also lognormally distributed? Possibly then it could be worth to perform the variographic analysis on a log porosity.

8. For sample S3 the REV is identified at 350 voxels, though only one permeability simulation is conducted. It would be nice to demonstrate that the calculated permeability is somewhat "continuous" by repeating the flow simulations on different subsets of that size of the original microCT image.

All other parts of the paper are satisfactory for me.

3 Technical comments

There are a very few typos in the text but given the necessity of more indepth revision from the authors I believe it's not useful to point them out now.

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