How representative is the conventional undisturbed soil core sample?

Kirill M. Gerke, Marina V. Karsanina

Schmidt Institute of Physics of the Earth of the Russian Academy of Sciences (IPE RAS), Moscow, Russia

EGU2020 – for live chat

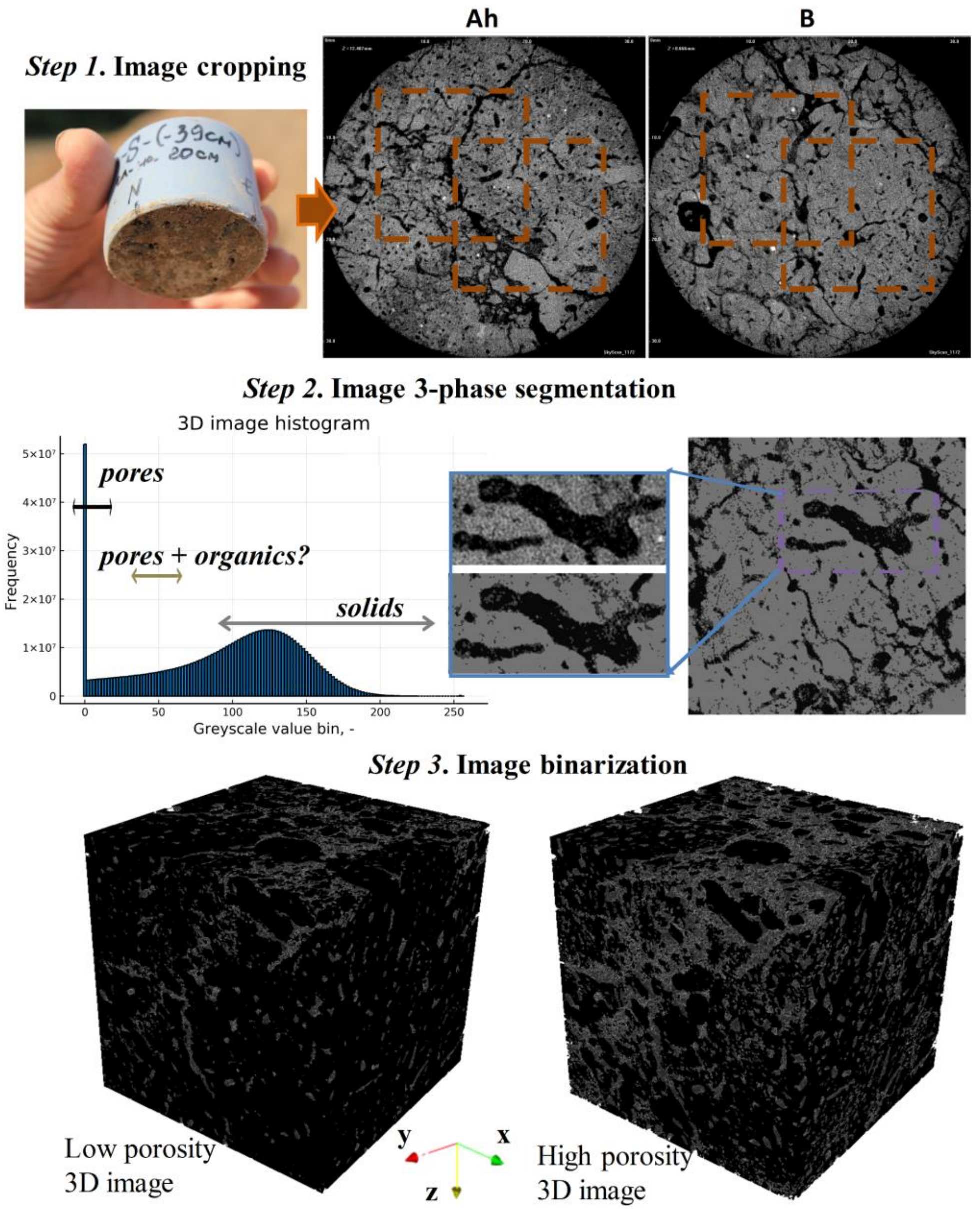


Figure 1. The general scheme of the image processing workflow. At Step 1 we crop cubes from the original X-ray microtomography scans. At Step 2 image is segmented into three phases using region growing algorithm. At final Step 3 we binarize resulted 3-phase segmentations into pores and solids. See text for more details.

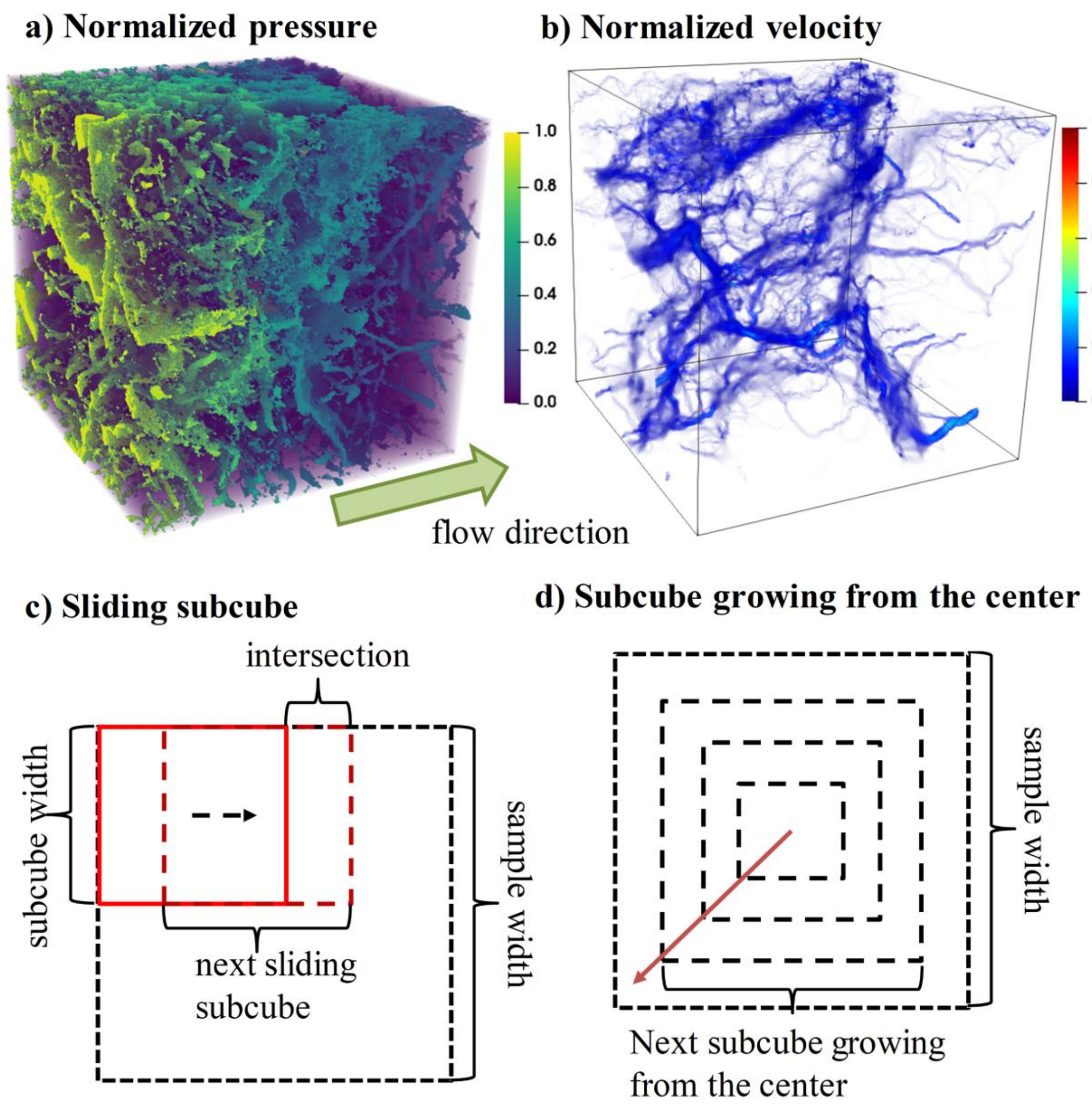
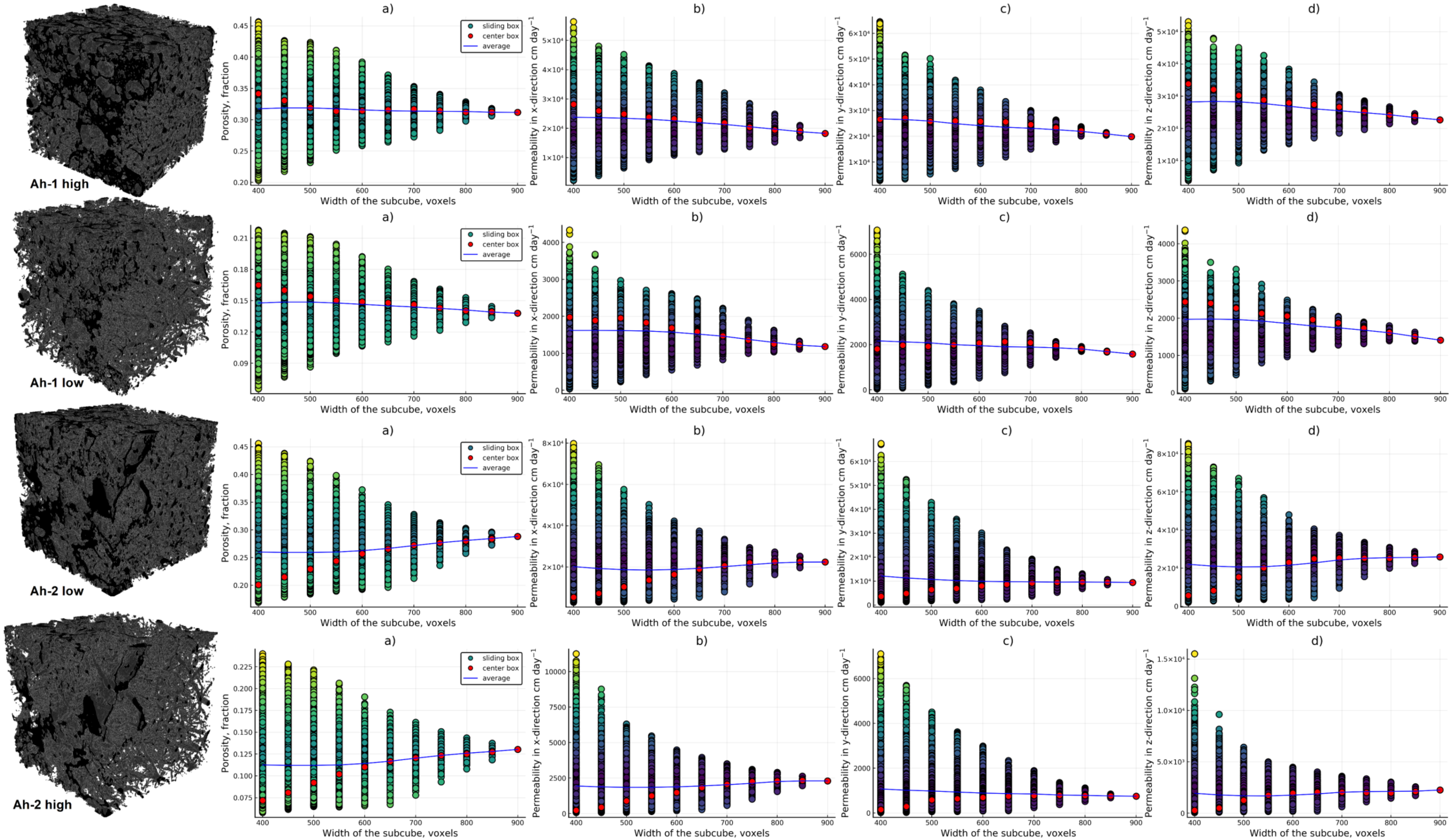


Figure 2. The REV analysis scheme based on the computed a) pressure and b) flow velocity fields for the whole sample's 3D pore geometry using either c) sliding subcube or d) subcube growing from the center of the sample approaches. Note, that for visualization purposes velocity field shown at b) is a scalar field (superposition of separate *x*, *y* and *z* velocity vectors).



R
E
V
?

Figure 3. The results of REV analysis for Ah soil sample: pore 3D images are shown on the left and their corresponding a) porosity, and saturated hydraulic conductivities in b) *x*, c) *y* and d) *z* directions computed within subcubes of different positioning and volume.

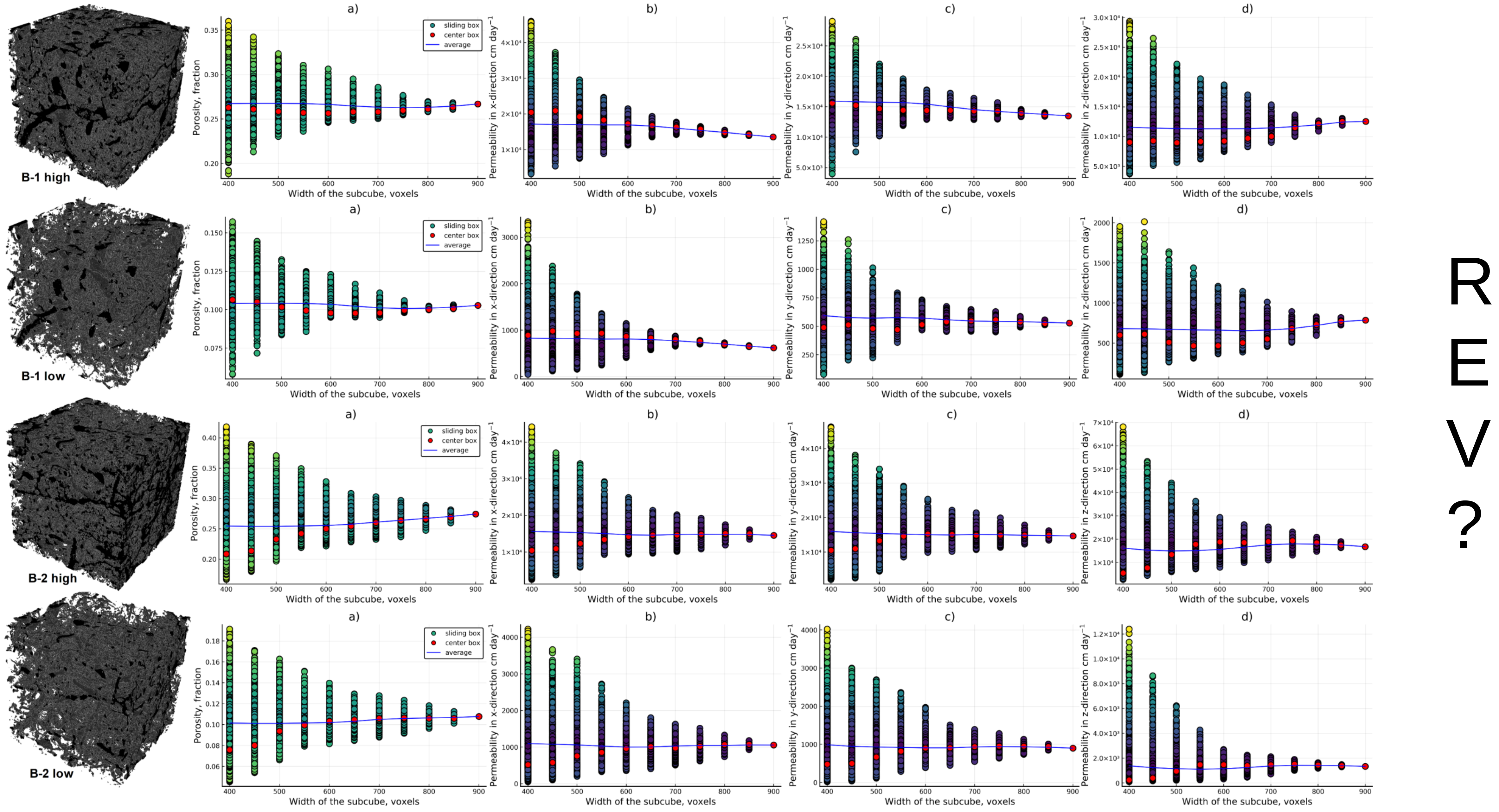


Figure 4. The results of REV analysis for B soil sample: pore 3D images are shown on the left and their corresponding a) porosity, and saturated hydraulic conductivities in b) *x*, c) *y* and d) *z* directions computed within subcubes of different positioning and volume.

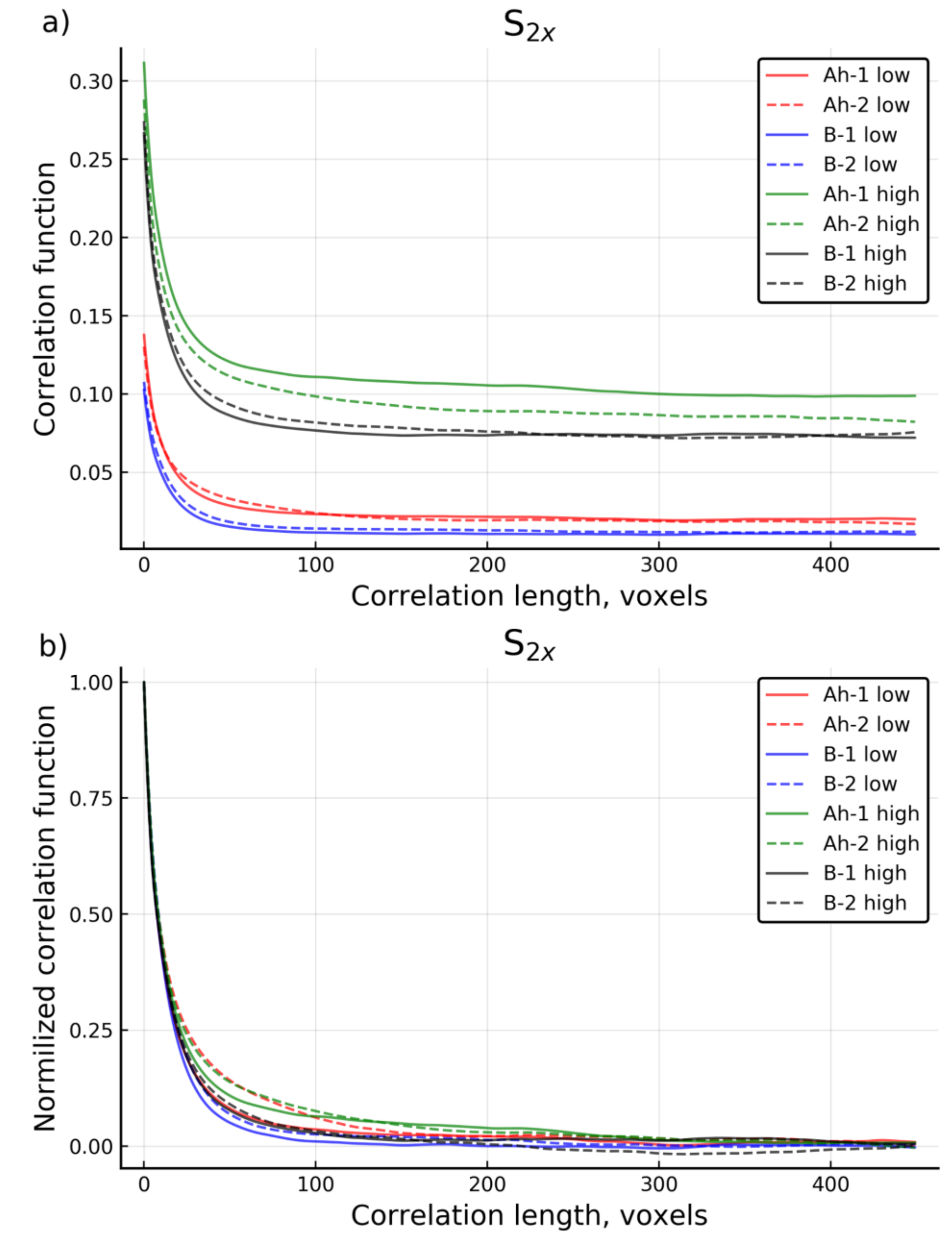
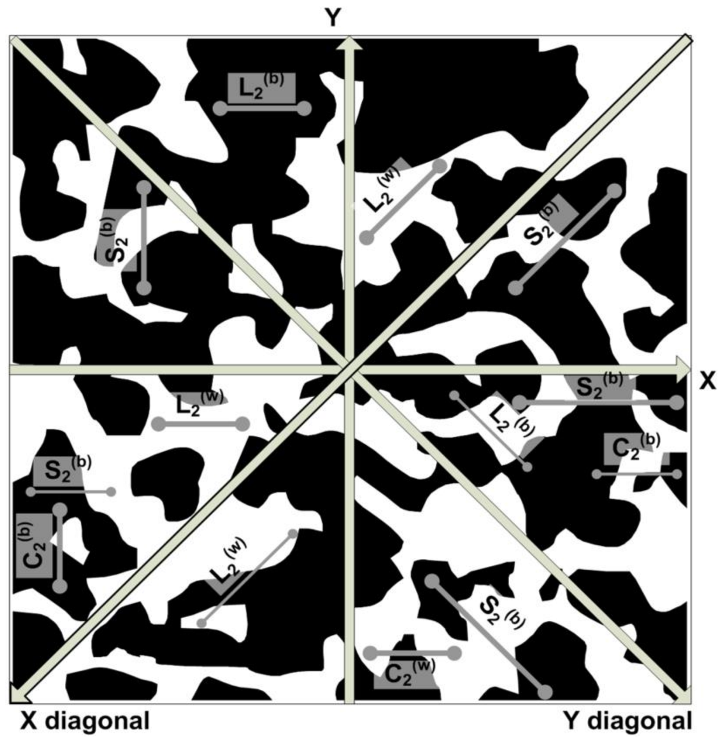


Figure 5. The example of non-normalized (a) and normalized S_2 correlation functions computed in x-direction for all 3D images. The difference *Err* according to Equation on the right is computed using the normalized values.



Calculation of directional correlation functions: S_2- two-point probability, L_2 – linear, C_2 – cluster functions.

$$S_{2norm}(\boldsymbol{r}) = \frac{S_2(\boldsymbol{r}) - \varphi}{\varphi(1-\varphi)}$$

Normalization by porosity for all utilized correlation functions: two-point probability, lineal, cluster and surface-surface.

$$Err = \sum_{\boldsymbol{r}} \left[f(\boldsymbol{r}) - \hat{f}(\boldsymbol{r}) \right]^2$$

The difference in structure between any two samples is them computed based on each correlation function- this provides a clear and meaningful measure of structural differences (in terms of each function).

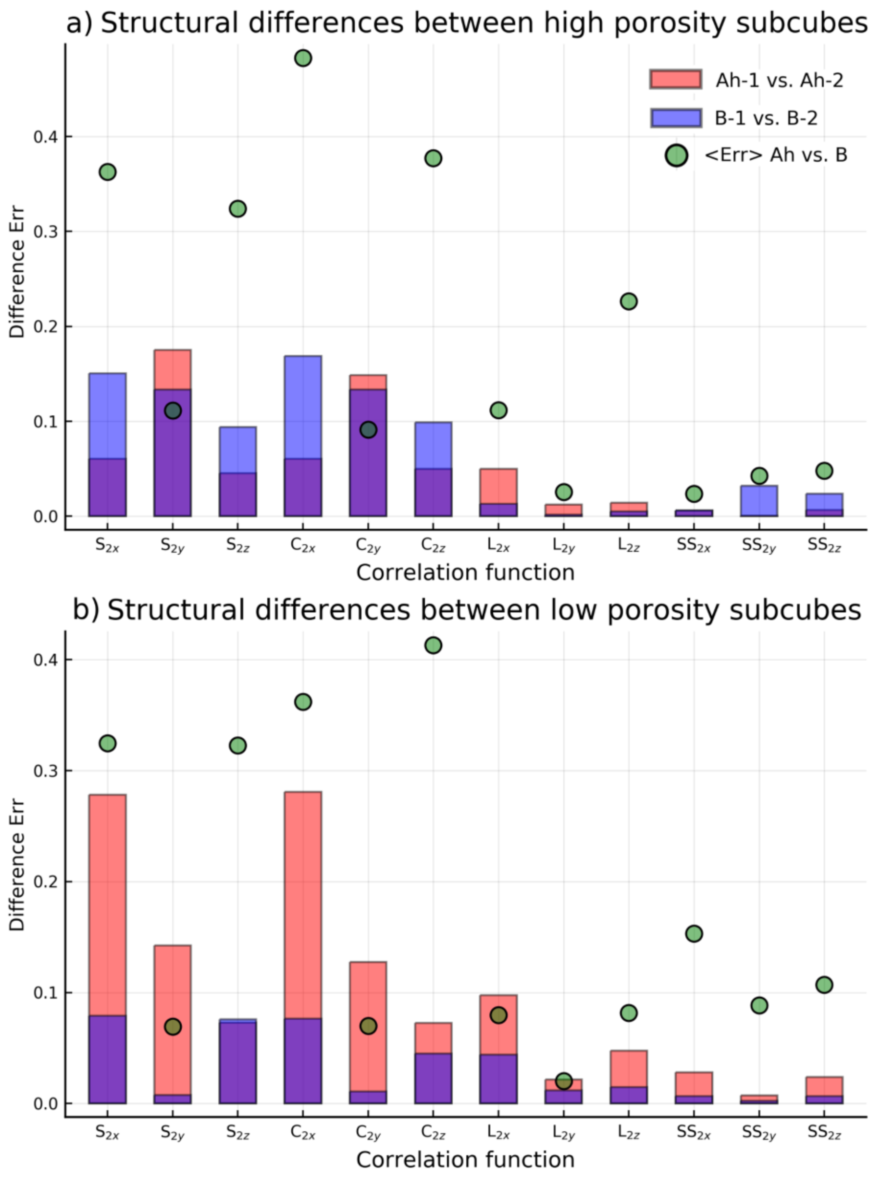


Figure 6. The results of structure comparison between the subsamples for low porosity (a) and high porosity (b) images. The red columns indicate the difference in terms of *Err* for Ah-extracted subsamples (Ah-1 vs. Ah-2), while blue – for B-extracted subsamples (B-1 vs. B-2). The green dots refer to *Err* values as computed by comparison of Ah and B samples and, thus, represent the significant difference as expected from soil structures from different horizons and having different genesis.

It is surprising to observe on Fig.6 that for all pairs except for B-1 vs. B-2 for low porosity images some CFs (e.g., S_{2y} and C_{2y} for both pairs for high porosity images, or L_{2x} and $L2y$ for Ah-1 vs. Ah-2 for low porosity) showed differences *Err* larger than those between Ah and B. In general, structural differences within Ah soil sample are much more significant that those within the B sample.

Both studied samples, while representing a single soil genetic horizon, are highly non-stationary and this is the major reason that REV concept in soil gets compromised. There are too many different porosity domains and soil genetic horizons are too small to negate such effects.

While the physical volume of our 3D images was around 3 cm^3, it is immediately clear that full soil cores are non-stationary for the same reason.

No ergodicity = no REV

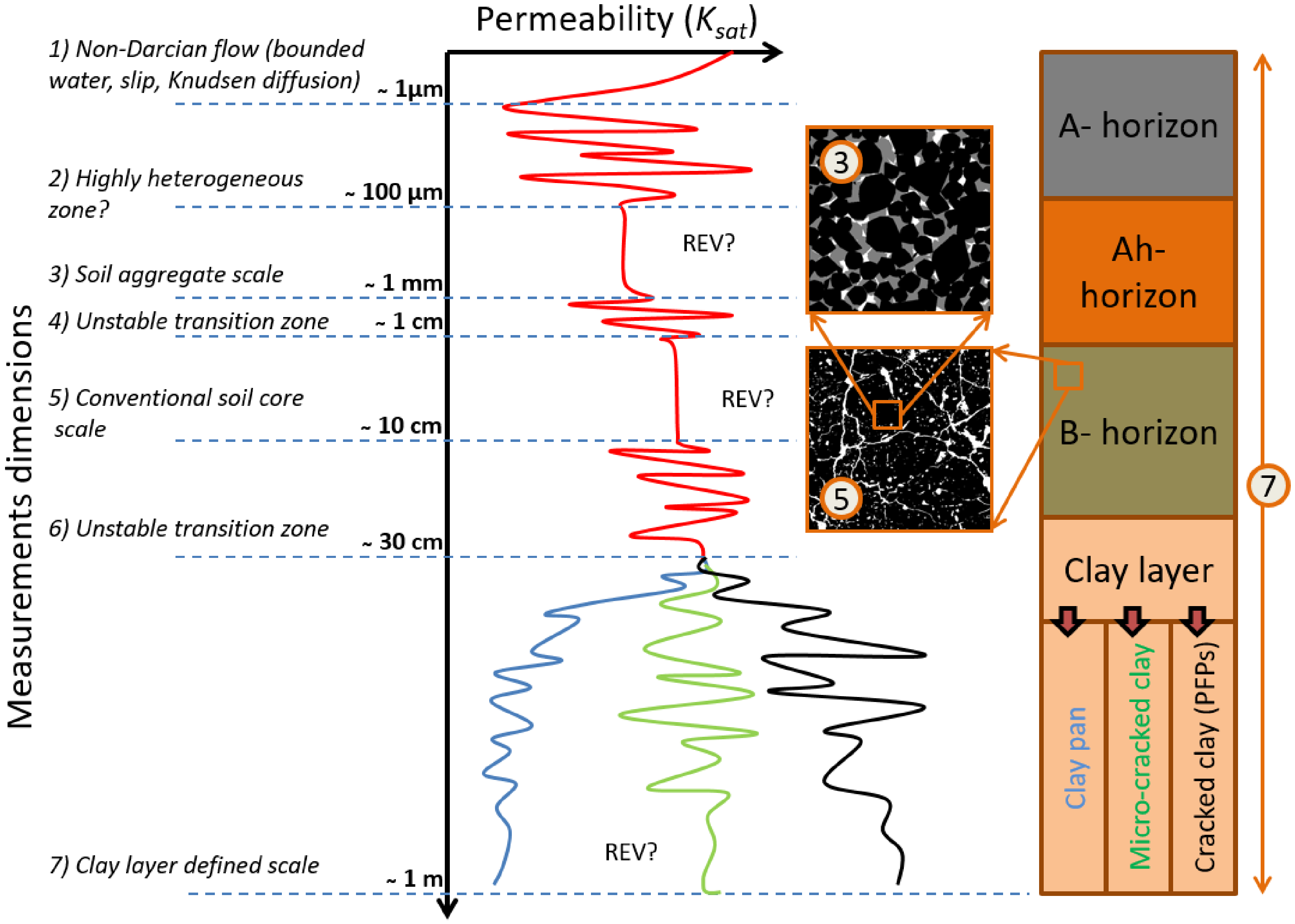


Figure 7. Schematic representation of different conventional structural levels within soil. On the left different such scale levels are provided. In the middle we hypothesize possible behavior of the permeability with increasing volume of measurements. Right side of the scheme shows possible horizons within the soil profile and hypothetic multi-scale soil structure for one of the layers. Note that this scheme aims to facilitate discussion and do not represent any real data or multi-scale measurements.

With the help of the hypothetical soil profile and stationarity analysis we were able to make a number of important observations:

- averaging flow properties of soil with non-stationary structure will likely result in abrupt changes with absent REVs;
- genetic soil horizons introduce such large inhomogeneities into soil profile, but it is not clear if the soil structure within the horizon can be considered to be stationary;
- averaging over several soil horizons will rarely if ever produce REV;
- the threshold to establish stationarity of a given soil structure based on any morphological metrics such as CFs is undefined;
- existing REV criteria were tested on close to stationary porous media such as sphere packings and homogeneous sandstones (Zhang et al., 2000; Li et al., 2009; Costanza-Robinson et al., 2011) and were found to be inapplicable to carbonates (Zhang et al., 2000) which better resemble soils as compared to other studies porous materials;
- the criteria to establish permeability REVs within porous media are, thus, undefined – existing criteria such as changes in K_{sat} below some threshold or expectation value lack spatial magnitude.

The paper with detailed description of all results is currently re-submitted after revision to *EJSS* journal. The title is "*How structure non-stationarity compromises flow properties representativity (REV) of soil samples: pore-scale modelling of saturated hydraulic conductivities*" (as the title of this presentation was fairly critiqued by the Reviewer2 – the volume of our modelling domains are smaller than conventional soil cores).

Most significant references for the methods used here:

- Karsanina, M. V., Gerke, K. M., Skvortsova, E. B., Ivanov, A. L., & Mallants, D. (2018). Enhancing image resolution of soils by stochastic multiscale image fusion. Geoderma, 314, 138-145.
- Gerke, K. M., Vasilyev, R. V., Khirevich, S., Collins, D., Karsanina, M. V., Sizonenko, T. O., Korost D.V., Lamontagne S., & Mallants, D. (2018). Finite-difference method Stokes solver (FDMSS) for 3D pore geometries: Software development, validation and case studies. Computers & Geosciences, 114, 41-58
- Karsanina, M. V., & Gerke, K. M. (2018). Hierarchical Optimization: Fast and Robust Multiscale Stochastic Reconstructions with Rescaled Correlation Functions. Physical Review Letters, 121(26), 265501.
- Gerke, K. M., Karsanina, M. V., & Katsman, R. (2019). Calculation of tensorial flow properties on pore level: Exploring the influence of boundary conditions on the permeability of three-dimensional stochastic reconstructions. Physical Review E, 100(5), 053312.

Acknowledgements

- This work was supported by Russian Foundation for Basic Research and Deutsche Forschungsgemeinschaft grant №20-54-12030 ННИО_а (simulations and analysis), and Russian Foundation for Basic Research grant №18-34-20131 мол_а_вед (X-ray microtomography and processing).
- We thank Pavel Chuyko for administrating our HPC resources. We are indebted to our colleagues – Prof. Aminat Umarova and Dr. Dmitry Korost for the help with soil sampling and X-ray microtomography. K.M.G. thanks Prof. Philippe Baveye for the encouragement to publish these results. We thank two anonymous reviewers who helped to improve this manuscript.