Pore space analysis of soil aggregates investigated by microtomography using synchrotron radiation

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Soil structure and particularly the formation of (micro)aggregates are important for long term sequestration of soil organic carbon (SOC). However, research during the last 50 years produced only a few quantitative studies that consider the interactive effects between soil biota and soil physical processes which are especially relevant on the micro-scale. Detailed knowledge of the geometry and continuity of the pore-network within soil (micro)aggregates is very important to close this gap since fluid movement (air and water) affects microbial activity in soil aggregates.

Recent advances in synchrotron radiation X-ray tomography and the development of algorithms to quantitatively describe porous media from reconstructed 3D images will greatly facilitate soil structure analysis on the micro-scale. This will contribute to understanding the mechanism involved in carbon sequestration within soil inter-aggregate pore space. For a statistical analysis of pore geometrical properties features like pore throat size, channel length and connectivity as well as pore size distributions within aggregates may be useful. Lindquist and Venkatarangan have developed a suite of algorithms assembled into a software package referred to as 3DMA to extract such geometric property distributions from 3D data sets [1]. The authors investigated the accuracy of their algorithms using a simulated image of packed hexagonal spheres. Relative errors between theoretical and numerically computed values were in general smaller than 5%. Also the analysis of microtomographic images of natural porous media (Fontainebleau sandstone) produced good results. To test the applicability of above mentioned algorithms for aggregated soil we have analysed a set of aggregates approximately 5 mm across at the synchrotron radiation source in Hamburg/Germany (DESY) (Fig. 1). From the reconstructed 3D images we extracted a brick shaped subvolume (2.50 x 2.25 x 1.60 mm) on which we determined pore statistical properties.

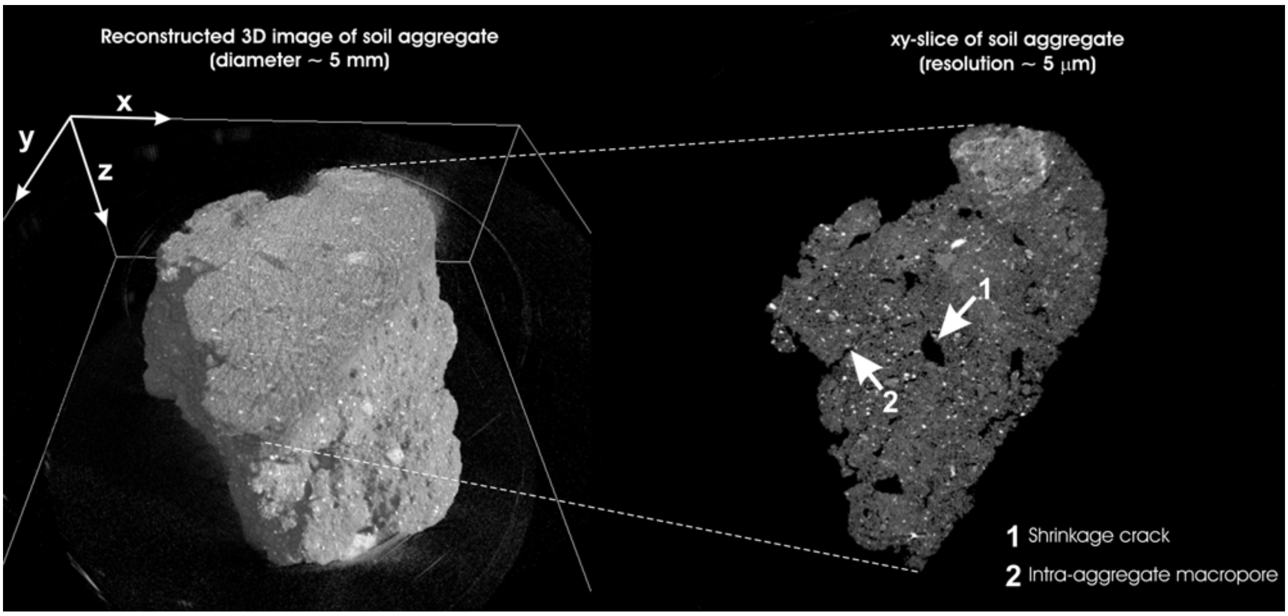

Figure 1: Reconstructed 3D image of a soil aggregate (left) and axial view on a xy-slice (right) revealing shrinkage cracks and inter-aggregate macropores. The microtomographic investigation was performed at beamline BW2 using a photon energy of 24 keV

Quantitative investigation of the geometry of the void space requires the distinction between voxels that represent solid phase and voxels that represent voids. This is achieved by an edge-finding segmentation algorithm [2] where two threshold attenuation coefficients T_0 and T_1 are chosen. Any voxel having intensity less than T_0 is identified as phase 0 (void) while voxels having intensities greater than T_1 are identified as phase 1 (solid). Voxels with intensities in the range $[T_0; T_1]$ are set using indicator kriging. Figure 2 shows the resulting segmented image which is in reasonable good agreement with the original microtomographic image.

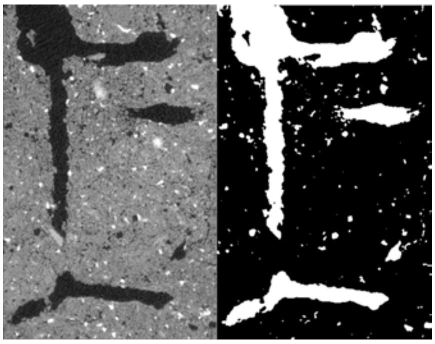

Figure 2: Original microtomographic 2D image (left) and segmented image resulting from the edge-finding algorithm (right). On the segmented image: black represents the solid phase and white the void space

To provide a representation of the network of potential flow paths the brick shaped subvolume has been skelotonized by the medial axis algorithm [1]. Apart from having a visual impression of the continuity and intersection of the flow path network medial axis construction is utilized as an embedded search structure to find specific sites such as pore throats in the object. With throats constructed, the pore space is divided into pores separated by throat surfaces from which pore-throat network statistics can be computed. Figure 3 shows a 3D view of the medial axis representing the flow network and shortest flow paths from the left to the right face of the subvolume.

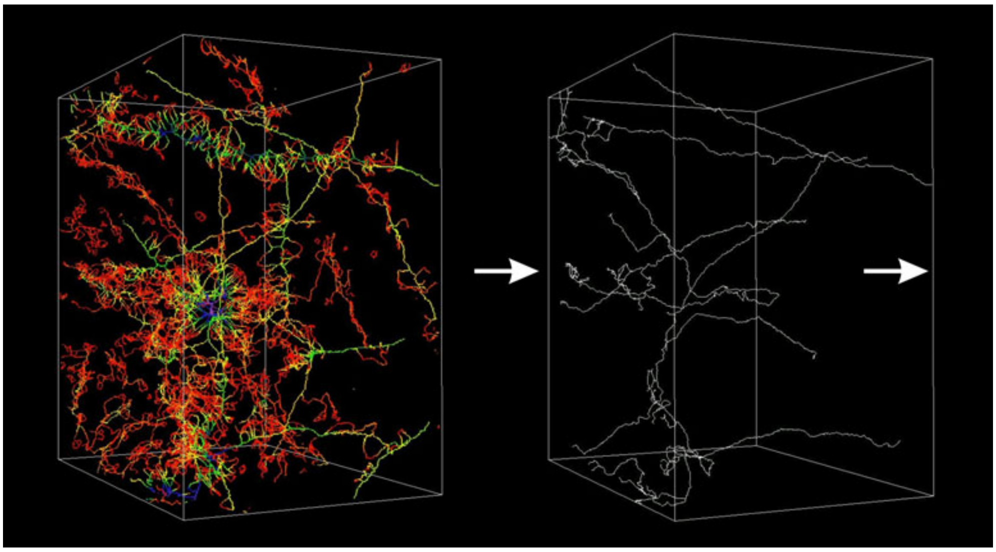

Figure 3: 3D medial axis plot showing pore channel tortuosity and connectivity (left). Shortest flow paths that connect the left and the right face of the subvolume are extracted (right)

The applied algorithms seem to be a promising tool for pore statistical analysis of soil aggregates. Further studies will focus on the effect of shrinking and swelling on changes in pore space properties.

References

[1] W. B. Lindquist and A. Venkatarangan, Journal of Geophysical Res. 105B, 21508-21528 (2000)

[2] W. Oh and W. B. Lindquist, IEEE Trans. Pattern Anal. Machine Intell. 21, 590-602 (1999)