Micropore Dynamics within Soil Aggregates from Forest and Agroecosystems

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Introduction

Soil aggregates are the primary repositories of carbon (C), water, microbial communities, plant nutrients, and pollutants within the soil profile. These biophysical polymorphic structures, ranging in size from submillimeter to many millimeters across, control the absorption, storage, and losses of most soil constituents. The dynamic properties of soil aggregates are controlled by the type of soil, anthropogenic inputs, daily changes in the weather, and plant root and soil animal activities. Current research suggests soluble C substrates are swept into interior pores of aggregates and retained by advective-dispersive flow properties associated with soil solutions. In relatively undisturbed regions of soil aggregates, root-derived C and subsequent C decomposition products, located within aggregate pores, contribute to the formation and stabilization of newly established internal pores in many feed-forward processes that influence mineral orientation, ionic charge, hydration phenomena, and microbial ecology.

Methods, Materials, and Discussion

Computer microtomographic (CMT) reconstructions of soil aggregates [1] provide many unique opportunities to identify pore geometries within these highly dynamic building structures of the soil profile. Intra-aggregate porosities are the primary storage sites of sequestered soil carbon. Associated respiratory activities of microbial communities generate gradients of oxygen deficiency within the central regions of aggregates. Oxygen gradients within aggregates control the genetic diversity of microbial communities and regulate the decomposition of C stored within these interior porous regions [2]. Renderings of CMT reconstructions into 3-D images greatly facilitate the visualization of numerous pore formation processes located inside natural soil aggregates (Fig. 1). More than 18 bottleneck- or dumbbell-shaped pores with diameters ranging from 5-10 to more than 100 μm (denoted by white arrows) can be identified within a single soil aggregate approximately 1000 μm across. These convoluted pores appear to be formed by extreme pneumatic pressures that accumulate while micropores fill with water during the frequent wetting cycles of natural soil aggregates. The voxel shapes of each new micropore appear to be the physical extension of an air-filled pore concurrently being filled with water. Its size and volume geometry appear to be a function of the soil biophysical forces that become plastic to the increasing dead-end pore pressures during the ensuing water front. Consequently, each wetting cycle builds more asymmetrical pore extensions and connectivities within specific regions within the soil aggregate, resulting in the various nonuniform "ink-bottlelike" connectivities known to cause the hysteresis effects of sorbed and desorbed water within porous media. Additional CMT evaluations of soil aggregates subjected to multiple wetting and drying cycles will confirm these working hypotheses that have been generated by the visualization of interior pores of natural soil aggregates.

The ink-bottlelike pores shown in Fig. 1 were extracted by using a boundary detection algorithm currently being developed at Michigan State University. The algorithm operates by performing a region-growing operation on gradient direction and magnitude encoding fields generated from the source volume. Once the encoding fields have been generated, it is possible to extract boundaries from the volume. By taking advantage of the gradient magnitudes and connectivity, constraints provided by the gradient direction field, a variant of region growing, can be performed on the encoding fields. The extraction algorithm operates by searching the encoding fields until an unlabeled voxel is found with a magnitude above some user-specified threshold. By using the unlabeled voxel as a seed point, a region that tracks the boundary is grown. In order to keep the region from straying from the boundary, the region is allowed to grow only by including neighboring voxels whose gradient encoding value is adjacent to the gradient encoding value for the seed voxel. This technique allows the extracted surface to wrap around objects but prevents the merging of voxels whose gradients point in radically different directions. All pores identified in Fig. 1 are connected to the outside of the aggregate and were extracted as part of the surface region.

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References

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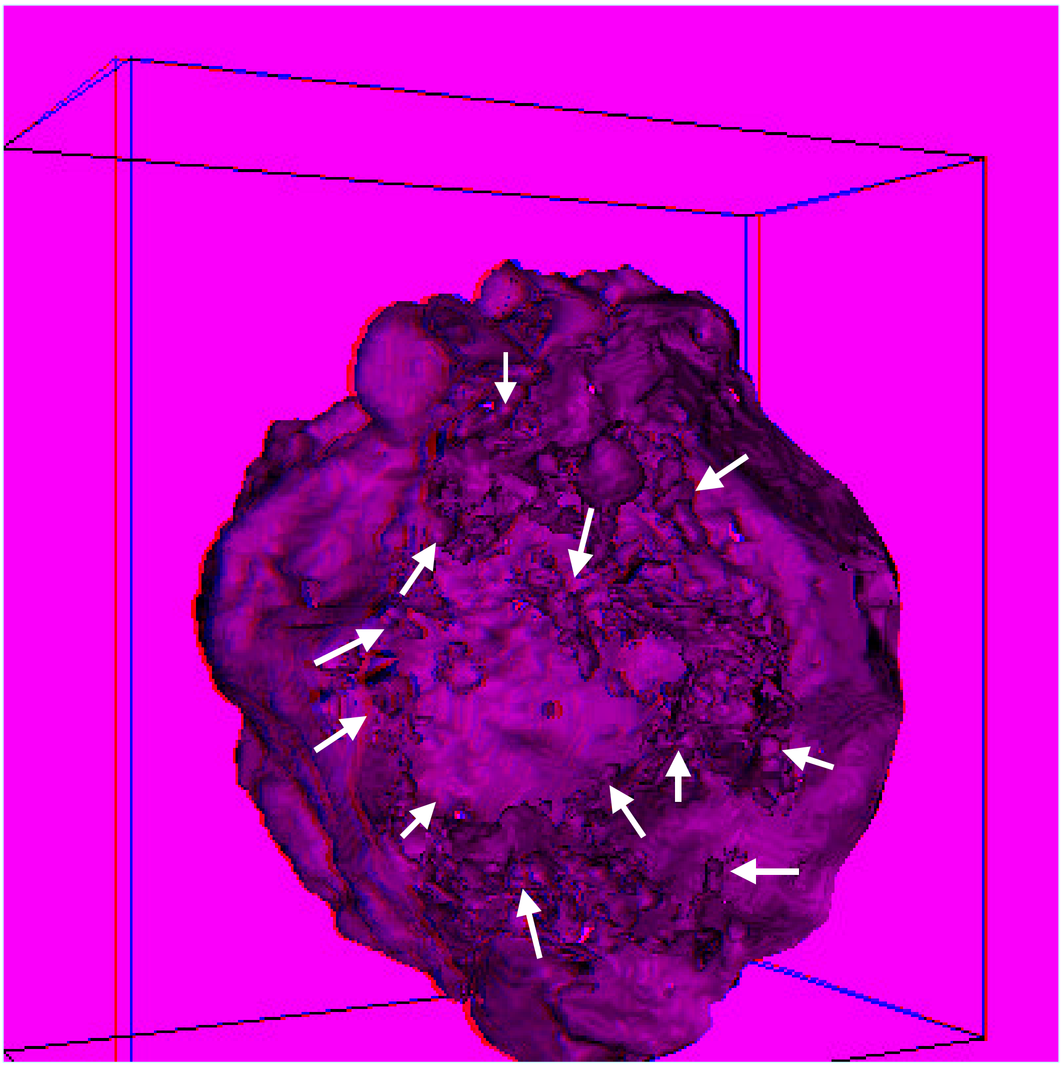

FIG. 1. Ink-bottlelike pores (indicated by arrows) developed by extreme pressure potentials within pores during sequential wetting by soil solutions. Each arrow, located with the aid of 3-D glasses, identifies specific pores displaying constricted "necks" that connect expanded spherical pores.