PhD thesis: Self organization of flow in dissolving rocks
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Abstract

In this thesis, we focused on three key questions related to dissolution patterns: What is the growth dynamics of dissolution channels (wormholes) in dissolving rocks, and how does the internal structure of the rock influence their shape? What is the effect of mixing at pore intersections on the shape of the dissolution patterns? And finally, how does dissolution alter the geometry of the pore space?

We investigated these issues by combining experimental data analysis with theoretical and numerical modeling. To study the growth dynamics of wormholes, we analyzed 3D tomographic images and time-lapse 3D tomography scans (so-called 4D tomography) of samples subjected to dissolution. We applied innovative segmentation methods to extract the geometry of wormholes from tomographic scans. Additionally, we studied geometric measures such as tortuosity and length wastefulness to analyze wormhole geometry. We demonstrated that wormholes evolve in a complex manner—accelerating, decelerating, and deviating from the main flow direction, depending on rock structure and flow intensity. We found that as the channel length increases, the hydraulic resistance of the system changes; however, the relationship between these variables is not linear, as previously assumed. The dynamics of this process result from the interaction of the growing channel tip with larger rock structures, such as packed areas with low porosity. These regions influence both the development rate and morphology of the channels: within them, the channel moves faster, spends less time inside, and branches less frequently. These observations were confirmed by analyzing the geometry of channels in two different types of rock.

To investigate the effect of reagent mixing at pore intersections on the shape of dissolution patterns, we performed numerical simulations using a network model. In the network model, pore space is represented as a network of interconnected capillaries whose diameter can increase due to dissolution. The studies showed that the dynamics of mixing at pore intersections significantly affect the morphology and propagation speed of dissolution channels. Specifically, it was found that at intermediate Damköhler numbers, the lack of mixing at pore intersections promotes faster development of dissolution channels, while at both higher and lower values of this number, the effect of mixing on the shape of dissolution structures is much weaker.

Finally, we investigated the impact of natural dissolution on pore geometry by analyzing tomographic scans of karstified rocks. This study revealed that the dissolution process leads to significant changes in pore structure, including pore merging and flow focusing, resulting in local increases in pore thickness and changes in flow tortuosity. These findings suggest that dissolution not only enlarges pores but also creates preferential flow paths, significantly altering the internal structure of the rock.