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Influence of layering on the formation and growth of dissolution pipes in karst systems

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In karst systems, hydraulic conduits called dissolution pipes (a.k.a. wormholes) are formed as a result of the dissolution of limestone rocks by the water surcharged with CO_2. The dissolution pipes are the end result of a positive feedback between spatial variations in porosity in the initial matrix and the local dissolution rate. A small enhancement in porosity at some point in the reaction front increases the fluid flow in that region, which convects reactant further downstream. By this means any local variation in porosity is amplified as the reaction front passes through and propagates downstream with the front, eventually developing into dissolution pipes. As dissolution proceeds the growing pipes interact, competing for the available flow, and eventually the growth of the shorter ones ceases.

Here, we investigate numerically the effect of rock stratification on the dissolution pipe growth, using a simple model system with a number of horizontal bedding planes, which are less porous than the rest of the matrix. Stratification is shown to affect the resulting piping patterns in a variety of ways. First of all, it enhances the competition between the pipes, impeding the growth of the shorter ones and enhancing the flow in the longer ones, which therefore grow longer. Next, it affects the shapes of individual dissolution pipes, with characteristic widening of the profiles in between the layers and narrowing within the layers.

These results are in qualitative agreement with the piping morphologies observed in nature. Importantly, measuring the ratio between the pipe diameters in different layers can provide one with information on the conditions prevailing during the formation of the pattern as well as on the physical characteristics of the layers in a given natural system.

Additionally, we have investigated the model with layers of the same porosity but a smaller dissolution rate. Interestingly, in this case, the stratification is shown to weaken the competition between the pipes.

Finally, we relate our results to the Laplacian path models, in which the growth takes place only at the tips of the long-and-thin fingers. This description, although simplified, turns out to capture many features of the dynamics of the dissolution pipe system and allows for the effective prediction of the resulting patterns.