SHAPES AND GROWTH VELOCITIES OF SOLUTION PIPES

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Cylindrical, vertical structures called solution pipes are a characteristic feature of epikarst, encountered in different parts of the world, both in relatively cold areas such as England and Poland (where their formation is linked to glacial processes) [1] and in coastal areas in tropical or subtropical climate (Bermuda, Australia, South Africa, Caribbean, Mediterranean) [2, 3]. They are invariably associated with weakly cemented, porous limestones and relatively high groundwater fluxes. Many of them develop under the colluvial sandy cover and contain the fill of clayey silt. Although it is accepted that they are solutional in origin, the exact mechanism by which the flow becomes focused is still under debate. The hypotheses include the concentration of acidified water around stems and roots of plants, or the presence of pre-existing fractures, which would determine the points of entry for the focused groundwater flows. However, there are field sites where neither of this mechanisms was apparently at play and yet the pipes are formed in large quantities [1]. In this communication we show that the systems of solution pipes can develop spontaneously in nearly uniform matrix due to the reactive-infiltration instability: a homogeneous porous matrix is unstable with respect to small variations in local permeability; regions of high permeability dissolve faster because of enhanced transport of reactants, which leads to increased rippling of the front. This leads to the formation of a system of solution pipes which then advance into the matrix. We study this process numerically, by a combination of 2d- and 3d-simulations, solving the coupled flow and transport equations at the Darcy scale. We quantify the factors which control the pipe diameters as well as their growth rates.

The most interesting result is the existence of two morphological phase transition in the finger shapes as the Peclet number is changed. At high Pe, well-separated, cyllindrical shafts are formed, of a nearly uniform diameter all along their lengths. They advance quickly into the matrix, with velocities several times larger than that of a unperturbed, planar dissolution front. Interestingly, this regime is analytically tractable, which allows us to derive the dependence of the pipe advancement velocity on the flow and reaction rate On the other and, for small flow rates, the pipes are funnel-shaped with parabolic tips and their advancement velocity is of the same order as that of a planar front. The transition between the two forms is abrupt, with no intermediate forms observed. The simulation results are compared with field evidence from limestone quarries in Smerdyna, Poland, where several hundred of solution pipes have been exposed. Interestingly, both forms (shaft-like and tunnel-like) are found in the field, sometimes in close proximity to each other.

Figure 1. Parabolic (left) and linear (right) solution pipes in the limestone quarry at Smerdyna (Poland). Photo on the right is courtesy of dr Łukasz Uzarowicz (Warsaw University of Life Sciences - SGGW, Poland).

References

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