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From viscous fingers to wormholes - interactions between structures emerging in unstable growth

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Dissolution of porous and fractured rock can lead to instabilities, where long finger-like channels or „wormholes" are spontaneously formed, focusing the majority of the flow. Formation of those structures leads to a significant increase in permeability of the system, and is thus important in many engineering applications, e.g. in acidization during oil and gas recovery stimulation. In this communication, we analyse this process using two different numerical models (a network model and a Darcy scale one). We show that wormhole patterns depend strongly on the amount of soluble material in the system, as quantified by the permeability contrast κ between the dissolved and undissolved medium. For small and intermediate values of κ, a large number of relatively thin and strongly interacting channels are formed. The longer channels attract shorter ones, with loops being formed as a result. However, for large values of κ the pattern gets sparse with individual wormholes repelling each other.

Interestingly, a similar succession of patterns can be observed in viscous fingering in a rectangular network of channels. In such a system, anisotropy of the network promotes the growth of long and thin fingers which behave similarly to wormholes. The attraction rate between growing fingers depends strongly on the viscosity ratio, I. The latter plays a role similar to that of permeability ratio for dissolution of porous material. To explain this behaviour, we have created a simple analytical model of interacting fingers, allowing us to quantify their mutual interaction as a function of finger lengths, distances between them and – most importantly – relative permeabilities. The theoretical predictions are in a good agreement with simulation data for both dissolution and viscous fingering processes.