

INSTABILITY OF AN INFILTRATION-DRIVEN DISSOLUTION-PRECIPITATION FRONT

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Infiltration of a rock by an external fluid very often drives it out of chemical equilibrium. As a result, alteration of the rock mineral composition occurs. It does not however proceed in the whole rock volume uniformly. Instead, there form one or more reaction fronts, i.e., zones of increased chemical activity, separating the altered (product) rock from the yet unaltered (primary) one. One of the simplest examples of such an alteration is the dissolution of some of the minerals building the primary rock. For instance, calcium carbonate minerals can be dissolved by infiltrating acidic fluids. In such a case the product rock has higher porosity and permeability than the primary one. Due to positive feedbacks between the reactant transport, fluid flow, and porosity generation, the reaction fronts in dissolution systems are inherently unstable. An arbitrarily small protrusion of the front gets magnified and develops into a highly porous channel. This feature of dissolution fronts, dubbed the “reactive-infiltration instability” [1], is responsible for the formation of a number of geological patterns, such as solution pipes. It is also of practical importance, since spontaneous development of localized highly porous flow paths is favourable by petroleum engineers, who apply acidization to oil-bearing reservoirs in order to increase their permeability.

However, dissolution might not be the only reaction in an infiltration-driven system. For instance, the products of dissolution might react with other species and reprecipitate [2]. The dissolution and precipitation fronts develop and start to propagate with equal velocities, forming a single replacement front. The porosity profile is not monotonic as in the case of pure dissolution, but it typically has a minimum in the vicinity of the front. Additionally, the porosity difference between the primary rock far-downstream and the fully developed secondary rock far-upstream can be either negative or positive, which either destabilizes or stabilizes the front.

We propose a theoretical model of a simple infiltration-driven dissolution-precipitation system. By performing linear stability analysis of the planar reaction front we show that the front can be unstable for a wide range of control parameters (the Péclet and Damköhler numbers, the ratio of molar volumes of the primary and the secondary mineral), even if the porosity of the secondary rock is lower than the porosity of the primary rock. Next, by numerical simulations of the complete dynamics we present the long-term evolution of the system. The nonlinear couplings between the flow, transport and the chemical reactions cause the development of an intricate pattern in the secondary phase (Fig. 1).

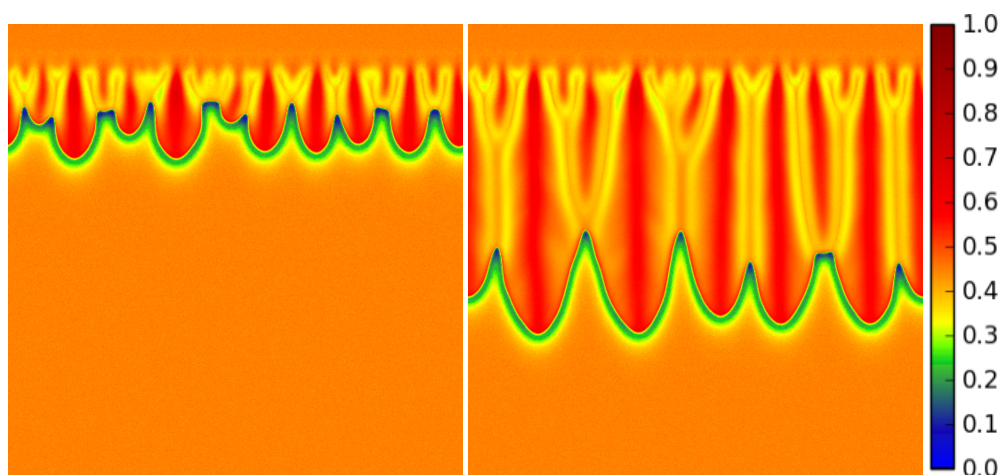


Figure 1. Development of a striped pattern in the secondary mineral phase during the infiltration-driven replacement process. The fluid flow and the reaction front propagation is from the top to the bottom. The colors correspond to different values of porosity.

References

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