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Dissolution in Fractured and Porous Rocks – the Cave Formation Paradox and Other Instabilities

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It has long been realized that limestone caves are solutional in origin; the carbonic acid-enriched groundwater forms a weakly acidic solution which dissolves the surrounding limestone as it percolates through the fracture network. Under the simplest assumptions - uniform flow and linear kinetics - the concentration of reactant decays exponentially with distance into the fracture, making it apparently impossible for long conduits to develop. How does the dissolution get so deep then? The answer until recently has been described in terms of changes in chemical kinetics: in natural calcite the reaction rate decreases by orders of magnitude near saturation, which gives a slightly undersaturated solution possibility to penetrate deeper into the fractured rock. Although this is an appealing and widely accepted resolution of the cave formation paradox, it turns out to be incomplete. Both the computer simulations [1] and laboratory experiments [2] show that a fracture does not necessarily open uniformly across its width, but can develop localized regions of dissolution. We show that there is in fact a universal instability in the equations for fracture dissolution [3], even under the most idealized circumstances: i.e. a fracture modeled as two parallel plates, laminar flow, and linear reaction kinetics at the fracture surfaces. This generic instability provides a more effective means to promote dissolution than changes in chemical kinetics and has a profound effect on how long it takes for breakthrough (when the fracture opens along its whole length) to occur.

This instability is related to a similar phenomenon in the reactive flow in porous rocks, first described by Chadam et. al [4] (so-called reactive-infiltration instability). The physical nature of both instabilites is different: the former is associated with an initial, uniform porosity state and the other with a steadily propagating dissolution front that separates regions of high and low porosity. We discuss the origin of both instabilities and the physical conditions under which they can be observed [5].

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