Geophysical Research Abstracts
Vol. 16, EGU2014-8983, 2014
EGU General Assembly 2014

Stability of sharp reaction fronts in porous rocks and implications for non-sharp reaction zones

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The flow of reactive fluids in the subsurface, like for instance acids, may create reaction fronts. A sharp reaction front is an idealization of the narrow zone where the reaction takes place. Narrow reaction zones are studied with a one-component reaction transport model, where a first order reaction changes the porosity. The porosity field is coupled to the permeability field, where an increasing porosity leads to an increasing permeability. Therefore, the reaction has a feed-back on the flow field. We have derived 1D approximate solutions for the change in concentration and porosity across the reaction zone. These solutions are used to derive a condition for reaction fronts to be narrow. The condition gives a minimum reaction rate necessary for 90% of the reaction to be restricted to the given area. Sharp fronts are idealizations of narrow fronts that are more amendable for analytical treatment. A condition has recently been derived for the stability of sharp reaction fronts in homogeneous porous medium using linear stability analysis. The condition gives that a perturbation of a flat reaction front of any wave-length becomes unstable if the permeability behind the front increases. The front instability grows faster for short wave lengths than for long wave lengths. Similarly, the perturbations of the front will die out if the permeability behind the front decreases, and short wave length perturbations will die out faster than long wave length perturbations. It is a condition that applies for both 2D and 3D porous media. Numerical experiments are shown that demonstrate the front stability criterion, when the fronts are narrow, but not sharp. The sharp front approximation turns out to be useful for the interpretation of reactions that are not sufficiently fast to give narrow reaction zones, when the reaction alters the porosity- and the permeability fields. Dissolution is an important example of reactions that increase the porosity and therefore the permeability. Numerical modelling shows that the flow field becomes directed towards tip of the reaction zone, because of the increased permeability towards the tip. This becomes the place where the Darcy flux is largest and where the reaction runs fastest. The largest Darcy flux at the tip implies a larger supply of reactive fluid at the tip than for the other parts of the reaction zone. Dissolution reactions are therefore unstable reactions, and they may be difficult to predict even though the data for the reaction kinetics is accurate. The same argumentation leads to that precipitation reaction propagate in a stable manner, since the precipitated minerals direct the flow away towards areas that have received less precipitation.