Modelling of reactive fluid transport in deformable porous rocks

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One outstanding challenge in geology today is the formulation of an understanding of the interaction between rocks and fluids. Advances in such knowledge are important for a broad range of geologic settings including partial melting and subsequent migration and emplacement of a melt into upper levels of the crust, or fluid flow during regional metamorphism and metasomatism. Rock-fluid interaction involves heat and mass transfer, deformation, hydrodynamic flow, and chemical reactions, thereby necessitating its consideration as a complex process coupling several simultaneous mechanisms. Deformation, chemical reactions, and fluid flow are coupled processes. Each affects the others. Special effort is required for accurate modelling of the porosity field through time. Mechanical compaction of porous rocks is usually treated under isothermal or isoentropic simplifying assumptions. However, joint consideration of both mechanical compaction and reactive porosity alteration requires somewhat greater than usual care about thermodynamic consistency.

Here we consider the modelling of multi-component, multi-phase systems, which is fundamental to the study of fluid-rock interaction. Based on the conservation laws for mass, momentum, and energy in the form adopted in the theory of mixtures, we derive a thermodynamically admissible closed system of equations describing the coupling of heat and mass transfer, chemical reactions, and fluid flow in a deformable solid matrix. Geological environments where reactive transport is important are located at different depths and accordingly have different rheologies. In the near surface, elastic or elastoplastic properties would dominate, whereas viscoplasticity would have a profound effect deeper in the lithosphere. Poorly understood rheologies of heterogeneous porous rocks are derived from well understood processes (i.e., elasticity, viscosity, plastic flow, fracturing, and their combinations) on the microscale by considering a representative volume element and subsequent averaging of microscopic constitutive laws. Micromechanical and thermodynamic modelling is performed in such a way that the consistency of the obtained rheology and thermodynamically admissible closed system of equations with the exact Gassman's relationship and Terzaghi effective stress law in the simplified case of poroelasticity is guaranteed.

In such environments as subduction zones or mid-ocean ridge, metamorphic rocks exhibit a lack of chemical homogenisation. Geochemistry suggests that in order to produce chemical heterogeneity, the fluids generated during high-pressure metamorphism must have been strongly channelled. The following three major mechanisms of fluid flow focusing have been proposed: fluid flow in open fractures and two different types of flow instabilities that do not require the pre-existing fracture network. Of the latter, the first represents a purely mechanical instability of Darcian flow through the deformable porous rock while the second is reactive infiltration instability. Both mechanical and reactive instabilities are expected to occur in the mantle and should probably reinforce each other. However, little research has been done in this direction. In order to investigate how the focusing of a fluid flow occurs, how mechanical and reactive infiltration instabilities influence each other, and what their relative importance in rocks with different rheologies is, linear and non-linear stability analysis is applied to derived governing equations.