

Controlling factors and modelling of reaction-induced stress and strain during water–rock reactions: Experimental investigation in $\text{CaSO}_4\text{--H}_2\text{O}$ system

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Dehydration and hydration reactions deep in the Earth control the water budget in the subduction zone system. Hydration reactions in particular, associate large solid volume changes. Such solid volume changes can induce large stress by the release of Gibbs free energy during the reactions, which can be larger than the strength of rocks and generate fracturing. However, whether the volume change in hydration reactions causes fracturing, enhance fluid flow and promote further hydration reactions, or it fills in the pores, reduces fluid flow and suppresses further hydration, is largely unconstrained. Here we explored mechanical responses of polycrystalline rock through hydration reactions $\text{CaSO}_4 + 2 \text{H}_2\text{O} \rightarrow \text{CaSO}_4 \cdot 2\text{H}_2\text{O}$.

In the previous study, we have conducted a systematic measurement of reaction-induced stress and strain using $\text{CaSO}_4\text{--H}_2\text{O}$ system, and have suggested that these properties are controlled by the competition of reaction rate and deformation rate. To further constrain the process, we measured time series variation of reaction rate, porosity reduction and deformation rate. At hydrostatic condition, the deformation (expansion) rate is always proportional to the reaction rate. Reaction rate are controlled by the reduction of reactive surface area as a function of porosity. After the rapid reduction of reactive surface area at critical porosity, we observe fluctuation of reaction rate as a function of time, indicating that permeability enhancement by reaction-induced fracturing. Under differential stress condition, dissolution–precipitation creep is induced, and the deformation can be express as the sum of expansion under hydrostatic condition, and shrinkage predicted from dissolution–precipitation creep law.

Based on these findings, the observed strain [ε] is well explained by the following parameters: reaction rate at the reactant surface [k_s], solid molar volume change of the reaction [ΔV_s], grain size distribution [$f(d)$], initial porosity [ϕ_0], critical porosity for reactive surface area reduction [ϕ_c], initial reactive surface area [A_0], and a reduction constant for reactive surface area [a].

These findings suggest that partial reaction is common for reactions with large positive solid volume change due to the local porosity closure, regardless of the fast surface reaction rate at geologic time. After the closure of the main pores, reaction-induced fracturing improves the connectivity of fluid, and further enhances reaction and fluid transport.

Keywords: Reaction induced stress, Reaction induced strain, Hydration reaction, Fluid, Serpentinization, Gypsum