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Role of reaction kinetics for replacement under differential stresses

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We present a simple quantitative model for mineralogical reaction at the grain scale under differential stresses. We study a cubic mineral out of equilibrium undergoing replacement by another cubic mineralogical assemblage in a thin fluid film located at grain junctions. The fluid pressure controlling the reaction in this film is equal to the normal stress on the grain boundary. The reaction affinity depends on pressure; it will hence depend on the grain boundary orientation, resulting in different reaction progresses for differently oriented grain boundaries. This will obviously influence the rock deformation, especially if it is dominated by dissolution/precipitation creep. The latter is often assumed to be the major deformation mechanism in many metamorphic rocks. The model is more general than a simple pressure solution model, since it includes net transfer reaction, but can still be used to model pressure solution. The evolution of the grain shape and the reaction progress with time depend on the Damköhler number (Da), which compares the timescales of diffusion and reaction. The preliminary results highlight the role of the differences in reaction kinetics on the overall replacement process. The stress term is important for the reaction rate especially if the metamorphic reaction occurs close to equilibrium. Then the effective reaction rate strongly depends on the orientation of the grain boundary with respect to the stress. A shape orientation is produced, resulting in a schistosity, if Da is small; e.g. the overall progress of the reaction is governed by the local reaction kinetics. For large Da – e.g. transport controlled reactions – the orientation effect is small. We will compare these predictions with texture observations in natural samples. We expect that slowly heated and pressurized rocks will have reacted close to equilibrium resulting in pronounced schistosity. This could explain the ubiquitous schistose rocks in subduction and collision orogens. We predict, that no schistosity should be observed in contact metamorphic environments, where reactions occur far from equilibrium (Roselle et al., 1997) even if strong differential stresses might be present close to the intrusion.

Roselle, G. T., Baumgartner, L. P., & Chapman, J. A. (1997). Nucleation-dominated crystallization of forsterite in the Ubehebe Peak contact aureole, California. Geology, 25(9), 823-826.