Kinetics of net-tranfer reactions between two minerals mediated by a fluid phase

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Metamorphic reactions in the crust generally consist of two elementary steps: material transport processes mediated by an intergranular fluid and reaction processes at the surfaces of participant minerals in the overall reaction. Many metamorphic rocks, especially rehydrated rocks, have various reaction textures indicating non-equilibrium or local-equilibrium, such as metamorphic banding and pseudomorphic structures. Classical metamorphic petrology usually focuses on the analysis of a 'perfectly equilibrated' system in which there is no need to consider various kinetic effects. On the other hand, the rich kinetic behaviors of reactions and material transport in a 'locally equilibrated' system have still been poorly understood.

A new kinetic model is proposed that illustrates the relative role of diffusion and surface reactions in the overall metamorphic net-transfer reactions involving solid solutions according to Lasaga (1986). In the model, three processes are formulated in a one-dimensional single-component system: (1) the kinetics of dissolution at the surfaces of two unstable minerals A and B, (2) the equilibration between the composition of a newly precipitated mineral and the concentration of the species in a surrounding fluid at each surface of the dissolving mineral, and (3) diffusion in a fluid-filled conduit connecting the two reaction fronts.

The behavior and the rate-determining process of a given system in the steady state depend on two non-dimensional parameters defined herein as g_A and g_B;

$$g_{(A,B)} = (k_{(A,B)} * K^{n-1} * L)/D$$

where k_A and k_B are rate constants of dissolution of minerals A and B, respectively, and n is a reaction order of dissolution assuming $n_A = n_B (= n)$. K is a solubility product of the precipitated mineral, L is a distance between A and B, and D is the diffusision coefficient in an intergranular fluid. If g_A and g_B are very small, the surface reactions are rate-controlling, and the compositions of the precipitated mineral on both sides of reaction fronts are same, that is, the system is homogeneous and 'perfectly equilibrated'. On the other hand, if g_A and g_B are very large, the material transport is rate-controlling, and the compositions of the precipitated mineral at the two reaction fronts are different, that is, the system is heterogeneous and 'locally equilibrated'.

Because the intergranular diffusivity (D) in the governing parameters, g_A and g_B, varies dramatically according to wetting characteristics of grain boundaries and the nature of aqueous fluid films (Nakashima 1995), the presence of fluid is one of the most important factors that control the mode of equilibrium and reaction textures in metamorphic and metasomatic rocks. In spite of oversimplification, our conceptual model has many significant implications for understanding the nature of fluid-rock interactions, and large applicability from sub-grain scale to subduction scale. Additionally, extension of our single-component model to multi-component multi-phase systems will make it possible to develop a new inversion method for kinetic parameters from mineral compositions in natural systems.