



Incipient fluid migration through the deep mantle by dissolution-precipitation: crystal growth constraints

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The mechanism and driving forces for transport of incipient C-O-H-bearing fluid/melt species through the Earth's mantle is a key issue in geosciences. Several mechanisms of the volatile transport, mainly solid state diffusion and fluid/melt porous flow have been considered. The grain boundary diffusion of hydrogen and carbon is in the range of 10^{-10} - 10^{-11} m²/s. These values suggest failure of the solid state diffusion hypothesis to explain melt migration. Since the extensive partial melting of the Earth's mantle seems improbable, the porous flow model of fluid or melt migration, accepted for the shallow upper mantle, can not be applied for the volatile transport through the deep mantle. At the mantle conditions water and carbonates are the excellent silicate solvents. Hence the migration of insulated portions of fluid through the solid matrix should proceed by means of the dissolution-precipitation mechanism. The major driving force for this process would be pressure or temperature gradient, differences in stable and metastable phase solubilities, and stress.

In order to estimate the reliability of proposed mechanism we measured migration rate of carbonate, water-carbonate, or water-rich liquid layer through the solid silicate matrix at the upper and lower mantle PT conditions. The thermal gradient was employed as a driving force. The kinetic constant of the migration rates were estimated to be 8×10^{-8} m/s/K for H₂O, 5×10^{-9} m/s/K for K₂Mg(CO₃)₂+2H₂O, and 3×10^{-10} m/s/K for K₂Mg(CO₃)₂ solvents. In order to extrapolate obtained data to the Earth we assumed that (a) mass transfer of silicate components through the melt layer is limited by diffusion and (b) the thickness of the melt layer is not enough to establish convection. The large lateral thermal gradient, 1-4 °C/km, proposed for mantle plumes reveals lateral fluid migration rate relevant to the plume lifetime (25-50 Ma). Nevertheless, the radial (vertical) migration rate is quite slow, about 1 km in 12.5 Ga. Obtained experimental data clearly demonstrate that dissolution-precipitation could be the predominant mechanism of volatile migration in the deep mantle. However, pressure or temperature gradients cannot be considered as major driving forces for this process.

The lower pressure silicate polymorphs may remain metastably in a subducted slab due to slow kinetics at low temperatures. At the same time the warming of subducted material should cause the decomposition of hydrous silicates and appearance of water-bearing supercritical fluid. The difference in solubility of stable and metastable phase is in order of tens wt.%, which is one order of magnitude higher than that realized in the experiments by using thermal gradient. This driving force can be most powerful and should cause the migration of fluids towards lower pressure and temperature conditions, until corresponding phase equilibrium and/or back incorporation of the fluid into hydrous minerals occur. Since the ratio of the strain rate to the diffusive flux in the upwelling mantle is significantly larger than unity, the re-equilibration of the texture by diffusion processes does not destroy that formed by straining the rock. The stress relaxation can be achieved by recrystallization through the liquid phase rather than by solid state diffusion or dislocation creep. In this case insulated fluid pockets will migrate towards maximum stress. The driving force for this process is the solubility difference of deformed and undeformed crystals in the fluid, which is caused by surface energy differences. This mechanism provides the migration rate in order of several μm per day, which is reasonably fast to explain fluid segregation in the upwelling mantle. Since melt formation and rock deformation in the mantle operate simultaneously in time and space, the fluid segregation by dissolution-precipitation can play important role in the melting in the Earth's mantle and can occur primarily at the subduction slab and mantle plume conditions, which would be the regions of most intense deformations.