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Mineral growth in rocks: interacting stress and kinetics in vein growth, replacement, and water-rock interaction

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ABSTRACT: Growth of crystals in rocks generates a local stress, or force of crystallization, which may drive pressure solution, deformation, or cracking of the host rock. Several novel feedbacks involving this local stress may account for replacement, certain deformation textures, earthquake triggering, and ore-body self-localization. Because the force of crystallization may modify (a) the rates of local phenomena such as mineral dissolution, mineral growth, and/or rock deformation, and (b) transport parameters such as permeability, porosity, and rock viscosity, and because it is itself modified by those phenomena and parameters in several potential feedbacks, models of water-rock interaction should be extended in particular cases to incorporate both the force of crystallization and its relevant kinetic consequences and feedbacks. We find equations giving the interrelated force of crystallization and growth rate for the widespread cases of replacement and vein growth. Driven by supersaturation, veins may grow not as cement in previously open fractures but by pushing the host rock apart as they grow, and promoting crack propagation.

1 INTRODUCTION

Growth of crystals or crystal aggregates in rocks necessarily generates a local stress, one long called – a bit inaccurately – force of crystallization. Through this local stress, the growing crystal or crystal aggregate makes room for itself within the surrounding rock in three possible ways: by dissolving, by displacing, or by fracturing its surrounding matrix. The continued growth of a crystal in a rock presupposes some supersaturation and needs sufficient transport of intergranular species to and from the growth site.

Because the force of crystallization is local, it naturally can interact with other local phenomena involved in its own genesis – specifically, with the very kinetics of the crystal growth that generates the stress, with the kinetics of pressure solution driven by it, with local transport properties, and/or with the rheology of local deformation or fracturing of the surrounding rock matrix. It is for this reason that water-rock-interaction calculations -- which utilize mineral growth and dissolution rates, and permeabilities and porosities – would become more realistic if they incorporated the force of crystallization.

Reaction-transport models now in use (e.g., Steefel & Lasaga 1994) do not provide for stress. Incorporation of force-of-crystallization models into geochemical water-rock reaction-transport calculations would warrant close consideration of the work of Bruton and Helgeson (1983), who studied the effects of fluid pressures different from lithostatic on water-mineral equilibria, and of Dahlen (1992), who clarified the relation between macroscopic and microscopic (e.g., non-local and local) stresses and their relation to water-mineral equilibria.

In short, because it is local, the growth-driven stress is able to enter into feedback with its own local consequences, kinetic or rheological. This is not possible for non-local tectonic or gravitational stresses, which cannot be modified by their local consequences.

Our purpose here is (a) to suggest new possible feedbacks involving the force of crystallization that may help explain the elusive problems of volume preservation in replacement, earthquake triggering, and ore body self-localization, and (b) to calculate the force of crystallization and model its kinetic and rheological consequences in two common occurrences of mineral growth in rocks, replacement and vein formation (Fletcher & Merino, 2000).

2 FEEDBACKS INVOLVING THE FORCE OF CRYSTALLIZATION

1) *Mineral replacement*. When a growing crystal pressure-dissolves the surrounding matrix, the force of-crystallization stress acts not only on the adjacent