The role of fluids in rock layering development: a pressure solution self-organized process revealed by laboratory experiments

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Natural deformation of rocks is often associated with stress-driven differentiation processes leading to irreversible transformations of their microstructures. The development mechanisms of such processes during diagenesis, tectonic, metamorphism or fault differentiation are poorly known as they are difficult to reproduce experimentally due to the very slow kinetics of stress-driven chemical processes. Here, we show that experimental compaction with development of differentiated layering, similar to what happens in natural deformation, can be obtained by indenter techniques in laboratory conditions. Samples of plaster mixed with clay and of diatomite loosely interbedded with volcanic dust were loaded in presence of their saturated aqueous solutions during several months at 40°C and 150°C, respectively. High-resolution X-ray microtomography and scanning electron microscopy observations show that the layering development is a pressure solution self-organized process. Stress-driven dissolution of the soluble minerals (either gypsum or silica) is initiated in the areas initially richer in insoluble minerals (clays or volcanic dust) because the kinetics of diffusive mass transfer along the soluble/insoluble mineral interfaces is much faster than along the healed boundaries of the soluble minerals. The passive concentration of insoluble minerals amplifies the localization of dissolution along some layers oriented perpendicular to the maximum compressive stress. Conversely, in the areas with initial low content in insoluble minerals and clustered soluble minerals, dissolution is slower. Consequently, these areas are less deformed, they host the re-deposition of the soluble species and they act as rigid objects that concentrate the dissolution near their boundaries thus amplifying the differentiation.

A crucial parameter required for self-organized process of pressure solution is the presence of a fluid that is a good solvent of at least some of the rock-forming minerals. Another general requirement for the development of such differentiated layering is the heterogeneous mixing of variously soluble and insoluble species. From a general point of view, the development of diagenetic or tectonic layering has crucial consequences in geological processes. The main one is to modify the composition and microstructure of rocks by dissolution of the most soluble species, passive concentration of the insoluble species and re-deposition of the dissolved species at a distance that depends on the transport efficiency (diffusion or advection). Consequently, layering development modifies both the rheological and the transfer properties of rocks. It is the most common strain localization process in the upper crust when a reactive fluid phase is present, complementary to other strain localization processes in the lithosphere. A specific effect is the development of anisotropic properties that may favor local sliding on weak surfaces. This is particularly important in fault zones where pressure solution processes are at work. Modeling of differentiated layering during natural deformation must be rooted in the stress-driven dissolution and transport properties of the various minerals forming the rocks, and on the evolution of their rheological properties. The strength evolution can be taken into account through a weakening factor in the zone of dissolution and a strengthening factor in the zone of deposition. The kinetics evolution is controlled by the critical parameters of pressure solution.