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Self-induced nanofluidic transport enables crustal-scale metamorphism

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The reaction of fluids with rocks is fundamental for Earth's dynamics as they facilitate heat/mass transfer and induce volume changes, weaknesses and instabilities in rock masses that localize deformation enabling tectonic responses to plate motion. During these fluid-rock interactions it is the ability of a rock to transmit fluid, its permeability, that controls the rates of metamorphic reactions. However, although some geological environments (e.g., sediments) are open to fluids, the majority of solid rocks (e.g., granites, elcogites, peridotites, etc.) are nearly impermeable. Surprisingly though, even in rocks that are nominally impermeable widespread fluid-rock interactions are observed leading to the question: How can fluids migrate through vast amounts of nominally impermeable rocks? Here we investigate one of the most wide-spread fluid-mediated metamorphic processes in the Earth's crust, the albitization of feldspatic rocks. We show that fluid flow and element mobilization during albitization is controlled by an interaction between grain boundary diffusion and reaction front migration through an interface-coupled dissolution-precipitation process. Using a combination of focused ion beam scanning electron microscopy (FIB-SEM)-assisted nanotomography combined with transmission electron microscopy (TEM) we show that the porosity is dictated by pore channels with a pore diameter ranging between 10 to 100 nm. Three-dimensional visualization of the feldspar pore network reveals that the pore channels must have been connected during the replacement reaction. Analysis of the pore aspect ratios suggests that a Rayleigh-Taylor-type instability associated to surface energy minimization caused the disconnection of the pore channels. Fluid transport in nanometer-sized objects with at least one characteristic dimension below 100 nm enables the occurrence of physical phenomena that are impossible at bigger length scales. Thus, on the basis of our microstructural investigations we used non-equilibrium molecular dynamics simulations to investigate the influence of nanoscale pore transport phenomena on metamorphic mineral replacement reactions. Our findings suggest that fluid transport through nanoscale transient pore networks may control regional-scale metamorphism and metasomatism.