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From porosity formation to permeability generation and the initiation of flow in dehydrating rocks

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Water escape from dehydrating rocks within the Earth's interior is a key process for long-term global water and element cycles. Existing fluid flow models require a priori physical assumptions (e.g., preexisting porosity) and cannot resolve the evolution from initial fluid production to flow channelization. In order to develop a model for this evolution, we need to unravel natural laboratories that display the incipient dehydration stages and the micro- to macro-scale fluid escape route evolution. The Erro-Tobbio meta-serpentinites (Italy) provide a unique snapshot into these early dehydration stages, recording the breakdown of hydrous antigorite to anhydrous olivine plus fluid and the formation of an olivine-vein network. We find that dehydration, fluid pooling, and flow initiation are controlled by micro-scale compositional rock differences. Our model starts with a rock in which all water is stored in solid and any preexisting porosity is negligible (zero-porosity case). Increasing temperature will initiate dehydration reactions, dividing the rock continuously into a dry solid and a fluid-filled porosity. Spatially variable reaction progress results in dynamically evolving porosity/permeability and heterogeneous fluid-pore pressure distributions. Fluid-pressure gradient relaxation causes fluid flow and its thermodynamic feedback triggers reactions to progress, resulting in a self-amplifying process.

Our new thermodynamic-mechanical model for reaction-porosity waves shows that fluid flow occurs solely in the reaction products and self-organizes into channelized fluid escape networks. This holds the key to formulating future quantitative models that address spatiotemporal processes such as the coupling between local fluid production and regional to global scale fluxes of elements.