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Fluid flow properties and growth drivers of serpentinite dehydration networks

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Despite the significant role volatiles in the deep earth play in major geologic processes such as volcanism, tectonics, and geochemical cycling, volatile release from hydrated rocks at depth remains an obscure process. To assess possible fluid escape mechanisms in the subducting slab, we investigated the Erro-Tobbio meta-serpentinites (ET-MS). These rocks preserve an extensive network of dehydration veins demonstrating the partial dehydration of serpentinite through the porosity-generating reaction of antigorite and brucite. Provided the vanishingly low background porosities in rocks at depth, the dehydration vein networks of ET-MS give us a glimpse of a potentially important self-organizing drainage mechanism for dehydrating rocks in subduction zones.

Our aim was to characterize the structure of these networks, evaluate upper limits of their hydrodynamic properties, and the dehydration network's morphological drivers. To do this, we coupled generative modeling with traditional microscopy and equilibrium thermodynamics. We trained generative machine learning models on CT-scans of hand specimens and images obtained by drone surveys of the ET-MS outcrops. Using these models, we generated samples of similar but varied vein network structures relative to their training data.

The structures of both the generated and real samples suggest these networks allow rapid percolation even at low porosities ($< 1\%$). Percolation analyses based on local vein diameters are also in agreement with predictions from thermodynamics and petrologic observations of ET-MS. This suggests that these network structures are equilibrium structures. Despite this, the network represents marked heterogeneous localization of porosity production in ET-MS caused by preconditioned structures and intrinsic spatial geochemical variation, particularly in the brucite distribution. Such porosity localization in a network structure further leads to much higher potential permeabilities ($K_{max.} \approx 5 \times 10^{-16}$) relative to homogenously distributed porosities of comparable values. We find that though bulk rock thermodynamics governs the total porosity generated in these rocks, internal compositional variations majorly impact the fluid flow properties of dehydrating serpentinite.