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Quantifying paleo-permeability on the deep subduction interface from exhumed rocks: a case study from Syros Island, Greece

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Slow slip and tremor (SST) has now been observed along many subduction margins worldwide, and the phenomenon is commonly linked to fluid and/or fluid pressure variations and migration. Crucial to understanding and modeling how fluids and seismicity might interact are estimates of porosity (Φ) and permeability (*k*) in and around the deforming subduction megathrust shear zone. Constraints on *k* from deeply buried metamorphic rocks are difficult to obtain, however. Experiments and some small-scale field observations indicate very low *k* for subduction-related lithologies, on the order of $10^{-18} m^2$ or less. However, thus far no attempts have been made to quantify the large-scale (or transient) permeability of subduction shear zones at deep metamorphic conditions.

Here we use structural, microstructural and geochemical observations on an exhumed sliver of metamafic rocks, with thermal conditions comparable to the Cascadia subduction zone, to quantify the hydrological properties of the deep SST source region. The study locality (Megas Gialos, Syros Island, Greece) records structures consistent with ductile deformation during subduction, underplating, and subsequent partial exhumation under high pressure greenschist facies conditions within the subduction shear zone.

The 100-m-length outcrop we studied consists of mafic greenschists with a strong ductile foliation and several generations of syn- to late-kinematic dilational faults and veins. Evidence for both along- and across-dip fluid flow is preserved in the form of metasomatic selvages parallel to the foliation, foliation-parallel quartz veins with foliation-perpendicular growth fibers, and dilational faults oriented at high angles to the foliation. The orientations and cross-cutting relationships between the foliation and multiple vein generations indicate the veins acted as transient fluid-flow conduits opened cyclically during background distributed viscous flow under extremely low differential stresses. In thin section, most of the veins exhibit crack-seal textures, consistent with episodic hydrofracturing.

To estimate the porosity and 2D permeability tensor from outcrops, we mapped the youngest generation of veins using high resolution drone models, then used Matlab-based software FracPaq to calculate permeability. Our assumptions include a) the latest generation of veins were at some stages opened simultaneously or in close succession (consistent with evidence for very low differential stress magnitudes), and b) the characteristic opening aperture was assumed to be an average of measured crack-seal widths in thin section. This approach yields an estimate of Φ of

~0.8 to 8% and an anisotropic *k* of 6.0×10^{-15} to 1.4×10^{-14} m^2 in the along-dip and across-dip orientations, respectively. These values are 3+ orders of magnitude greater than would be inferred for the background unfractured rock. They are broadly consistent with estimates of *k* from geophysical observations of tremor migration patterns, and with models of the permeability contrasts (background/transient) required for viscous compaction of fluid pressure to lead to unstable slip. The method we demonstrate can be applied to other outcrops with subduction contexts and can provide essential ‘ground-truthed’ data to test assumptions of fluid flow in the deep tremor source region.