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Deciphering the combined structural and mineralogical record of serpentinite fault rocks

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Serpentinites and associated metasomatic rocks play a critical role in controlling the rheology of faults and shear zones in important tectonic settings worldwide. Deciphering the combined structural and mineralogical record of deformed serpentinites has the potential to elucidate deformation processes, reveal fault kinematics, and track the evolution of environmental conditions during deformation. However, differentiation of serpentine minerals is challenging, and many approaches are destructive, making mineralogy difficult to relate to microstructure and deformation mechanisms. We applied Raman spectroscopy mapping, combined with scanning- and transmission-electron microscopy, and X-ray microtomography, to provide new insights into the deformation behaviour of serpentinite-bearing fault rocks from an ancient, exhumed shear zone (Dun Mountain Ophiolite, New Zealand), and the surface exposure of a modern, active fault (San Andreas Fault, California).

While fabrics in the surface fault gouge exposure of an active fault differ substantially from exhumed fault rocks formed at depth, the physical processes that govern serpentinite deformation and mineral reactions are fundamentally similar. We highlight these similarities and the methodologies required to decipher these fault rock fabrics through the detailed study of a crack-seal vein from the Dun Mountain Ophiolite and a sample of fault gouge from the San Andreas Fault. Analyses of a mineralogically banded serpentinite-hydroandradite crack-seal vein from the Dun Mountain Ophiolite yield new constraints on the 3D structure of crack-seal veins, provide insights on dissolution-precipitation processes during vein formation, and reveal a unique mineralogical record for repeated rapid crack opening, potentially associated with repetitive stress drops such as those recorded during episodic tremor. A study of actively deforming serpentinite clay fault gouge reveals evidence for broadly distributed deformation. The microstructure and mineralogy record the process of gouge formation through the combined mechanical (brittle) and chemical (dissolution-precipitation) deformation of clasts of a wide range of lithologies (serpentinite, metabasalt and metasedimentary rocks), with evidence that these processes have facilitated the near surface in situ saponitification and carbonation of serpentinite.

Our work reveals that dissolution-precipitation processes, combined with brittle deformation control rheological behaviour in both deep and shallow serpentinite faults, and can be revealed through detailed micro -mineralogical and -structural characterisation.