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Frictional anisotropy of antigorite and its impact on thrust-fault mechanics at subduction zones

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There is general consensus that the forearc mantle wedge at subduction environments is hydrated by aqueous fluids released during subduction by dehydration reactions occurring in the slab lithologies, at increasing pressure and temperature. At these conditions, the most abundant mineral phase characterising hydrated harzburgites is serpentine, stable at temperatures of 650–700 °C, at pressures corresponding to 30-60 km depths, whose occurrence may have important implications in the rheology of the forearc mantle wedge. In the last decades, efforts have been employed to unravel the seismic shear-wave anisotropy measured in many subduction systems, traditionally attributed to the crystal preferred orientation of olivine and/or serpentine in the mantle wedge. However, little is known about the implications of such preferred orientation, which likely has its origin at the slab-mantle interface, on the frictional behaviour of a large-scale thrust fault with cumulative slip.

In this framework, we focussed on the mechanism of frictional anisotropy, which manifests through a dependence of the magnitude of friction force on slip direction and through the presence of friction force components transverse to the slip direction. This phenomenon is encountered for sliding surfaces having a structured, anisotropic morphology or nanoscopic corrugations related to the surface crystal structure. Among minerals with a prominent role in defining the mechanical behaviour of faulted regions, antigorite, the high-temperature, high pressure polymorph of serpentine, exhibits inherently nanostructured basal surfaces with an orthotropic symmetry. A new approach for the study of the crystal structure-frictional behaviour relationship is the nanotribological characterization performed with a scanning force microscope, now applied for the first time to natural antigorites. In this setup, a micrometric tip mounted on an elastic cantilever is scanned by piezoelectric actuation along all directions of the sample surface on a nanoscopic area, while vertical deflection and lateral torsion of the cantilever are monitored in real-time, allowing for the quantitative determination of the friction force vectors. The experiments allow us to assess a strong frictional anisotropy of antigorite basal surface, crystallographically related to its peculiar wavy arrangement of the TO-layer and the presence of reversals occurring along the a-axis of the tetrahedral sheets. Individual domains in antigorite single crystals show frictional anisotropy as high as 100%. This observation, if associated to the known strain-induced lattice preferred orientation of serpentine rocks, allows us to infer a strong anisotropic frictional behaviour of sliding surfaces of serpentinized rocks in subduction zones. On this basis, we review major models describing the mechanics of faulted regions which, so far, postulate a pure isotropic behaviour of the friction phenomenon. Particular emphasis is dedicated to subduction geometries characterized by obliquity. Impressive phenomena can be envisaged if frictional anisotropy is introduced in the dynamical description of faults such as mechanical instabilities giving rise to anomalous seismic degree of partitioning and a monotonic behaviour, rather than saturated, of the slip vector residual angle as a function of obliquity.