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Surface structure-frictional anisotropy relationship of phyllosilicate crystals and its implications on fault mechanics

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The inherent lamellar structure of phyllosilicates entails their basal surface to be the preponderant one in contact with the environment and to directly participate to pertinent geophysical and geochemical processes. The knowledge of the surface structure of such minerals is therefore the starting point for understanding their chemical and physical behaviour. We focus here on the frictional response of the basal surface of phyllosilicate minerals through a nanotribological approach based on the exploitation of scanning force microscopy-based techniques. 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. This atomic-scale approach enables to relate the frictional response to the surface structural features, e.g., to relate the anisotropy deriving from the symmetry of the arrangement of surface atoms with the anisotropy of friction. This latter phenomenon 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. It is characteristic of sliding surfaces having a structured, anisotropic morphology or nanoscopic corrugations associated to the surface crystal structure. Among phyllosilicates, antigorite, the high-temperature, high pressure polymorph of serpentine, exhibits inherently nanostructured basal surfaces with an orthotropic symmetry. In our evaluation, we assessed a strong frictional anisotropy of the antigorite basal surface in relation to other phyllosilicates such as mica muscovite. We relate this strong anisotropy to the peculiar wavy arrangement of the TO-layer of antigorite 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%. If we take into account the known strain-induced lattice preferred orientation of serpentine rocks, which is responsible for the seismic shear-wave anisotropy measured in many subduction systems, we can assume also a strong anisotropic frictional behaviour of sliding surfaces of serpentinized rocks occurring in regions where strain and slip processes are active, such as the thrust faults in subduction zones. On this basis, we show which are the effects of frictional anisotropy on slip trajectories of sliding interfaces, with particular emphasis to subduction geometries characterized by obliquity. On the basis of the development of specific preferred orientations, different phenomena can be envisaged. In some cases, we identify a weakening behaviour, which substantiate the aseismic character of certain fault segments. In other cases, we identify a hardening behaviour, which is associated to the onset of mechanical instabilities giving rise to anomalous seismic degree of partitioning.