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Exploring fault rocks at the nanoscale

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The mechanical properties of a fault are strongly dependent on mineralogy and microstructure of the fault rocks. X-ray diffraction (XRD) methods, combined with optical and scanning electron microscopies (OM and SEM, respectively), are the conventional tools to investigate bulk mineralogy and microstructures of the fault rocks.
However, fault rocks are often formed by ultrafine-grained minerals (below 1 - 2 microns, i.e., below the resolution limits of OM and SEM), requiring the use of a high-resolution technique, such as the transmission electron microscopy (TEM), that combines images, diffraction and chemical data, down to the nanoscale.
Here, I summarize a few examples of TEM study on fault rocks, obtained from both nature and deformation experiments and covering different kinds of rocks, from carbonates to ultramafics and quartz-feldspatic rocks. In particular:
1) Mineralogical and micro/nanostructural study of fault core samples from the Zuccale low-angle normal fault (Elba Island, Italy; carbonatic protolite). TEM investigation showed large amounts of oriented and interconnected talc lamellae, affected by intense interlayer delamination, giving rise to "sublamellae" down to 10 - 20 nm thick. This peculiar nanotexture suggests easy frictional sliding along an almost infinite number of sliding surfaces, thus explaining the weakness of this fault.
2) Mineralogical and micro/nanostructural characterization of the slip zones produced by high-velocity friction experiments on carbonatic and ultramafic rocks. TEM investigation of the slip zones revealed thermal decomposition (by frictional heating) of the starting minerals (dolomite and antigorite, respectively), and allowed the accurate characterization of the high-temperature, ultrafine-grained mineral assemblages (grain size from a few nm to 200 nm).
3) Mineralogical and micro/nanostructural study of a natural pseudotachylite in quartz-feldspatic rocks (northern Victoria land, Antarctica), showing thermal decomposition and subsequent re-crystallization of K-feldspar.
The examples above show that TEM can be a powerful tool to detect deformation-induced transformations within fault rocks, often taking place at a sub-micrometer scale. These transformations include mineral reaction, decomposition and re-crystallization processes, crystal defects, preferred orientation, formation of poorly-crystalline to amorphous materials, i.e., all those features that can play a fundamental role in the mechanical behaviour of a fault rock.