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Time and space evolution of an active creeping zone: competition between brittle and ductile deformations, new insights from microstructure studies of SAFOD (San Andreas Fault Observatory at Depth) samples.

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Creep processes can relax an important part of the tectonic stresses in active faults, either by permanent steady-state creep or by episodic post-seismic creep. Here, our goal is to better constrain the micro-physical parameters that control this transition between seismic and aseismic behavior, both in time and in space.
We present new results from microstructural studies on natural samples collected from the SAFOD (San Andreas Fault Observatory at Depth) drilling project, located on the Parkfield segment of the San Andreas Fault (SAF). Seven samples were collected from the main active creeping zone: the Central Deforming Zone at 3296,6-3299,1m depth (relative to Phase 3 Core). We performed chemical and mineralogical analyses and microscope observations on twenty thin sections cut from those samples. In a previous study (Gratier et al., Geology, 2011), we have already shown that pressure solution creep is an active deformation process in the SAF.
We propose a model of microstructural evolution to characterize in which conditions pressure solution creep is efficient enough to relax stress and to prevent the nucleation of moderate to large earthquakes. We show that two crucial parameters may accelerate pressure solution: the presence of phyllosilicates and the degree of rock fracturing. The initial structure and composition of the rocks may explain why pressure solution creep is efficient or not. Moreover, both the content of phyllosilicates and the degree of fracture may evolve with time at various scales during the seismic cycle:
- During interseismic periods (years to millennia): fracturing activates postseismic creep. However, the progressive healing of the fracture annihilates this effect. Meanwhile, growth of phyllosilicate minerals, associated with postseismic fluid flow may also activate the creep rate.
- During much longer geological periods (hundred thousands to millions of years), the composition of gouge material deformed by pressure solution evolves by the passive concentration of phyllosilicates due to the dissolution of soluble minerals. If their content is large enough, phyllosilicates could control the creep mechanism and accommodate the deformation by friction on clay layers.
The steady state creeping zone of the SAF illustrates both effects thanks to very fine grains resulting from successive fracturing processes, very few amount of healing, possible growth of metamorphic clays and a general passive concentration of phyllosilicates with volume decrease. Conversely, in the nearby damaged zone, healing reduces the efficiency of pressure solution. Microseismicity, resulting from the fracturing of healed zones, may maintain a dynamic equilibrium between fracturing and healing. The southern part of the permanent creeping zones, which shows 20-30 years "Parkfield"-like earthquake cycles with postseismic creep, may illustrate the competition between healing/strengthening and creep processes that occur during interseismic periods.