Geophysical Research Abstracts
Vol. 12, EGU2010-6563-1, 2010
EGU General Assembly 2010

How clays weaken faults.

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The weakness of upper crustal faults has been variably attributed to (i) low values of normal stress, (ii) elevated pore-fluid pressure, and (iii) low frictional strength. Direct observations on natural faults rocks provide new evidence for the role of frictional properties on fault strength, as illustrated by our recent work on samples from the San Andreas Fault Observatory at Depth (SAFOD) drillhole at Parkfield, California. Mudrock samples from fault zones at ∼3066 m and ∼3296 m measured depth show variably spaced and interconnected networks of displacement surfaces that consist of host rock particles that are abundantly coated by polished films with occasional striations. Transmission electron microscopy and X-ray diffraction study of the surfaces reveal the occurrence of neocrystallized thin-film clay coatings containing illite-smectite (I-S) and chlorite-smectite (C-S) phases. X-ray texture goniometry shows that the crystallographic fabric of these faults rocks is characteristically low, in spite of an abundance of clay phases. 40Ar/39Ar dating of the illitic mix-layered coatings demonstrate recent crystallization and reveal the initiation of an "older" fault strand (∼8 Ma) at 3066 m measured depth, and a "younger" fault strand (∼4 Ma) at 3296 m measured depth. Today, the younger strand is the site of active creep behavior, reflecting continued activation of these clay-weakened zones. We propose that the majority of slow fault creep is controlled by the high density of thin (< 100nm thick) nano-coatings on fracture surfaces, which become sufficiently smectite-rich and interconnected at low angles to allow slip with minimal breakage of stronger matrix clasts. Displacements are accommodated by localized frictional slip along coated particle surfaces and hydrated smectitic phases, in combination with intracrystalline deformation of the clay lattice, associated with extensive mineral dissolution, mass transfer and continued growth of expandable layers. The localized concentration of smectite in both I-S and C-S minerals, which probably extends to greater depths (<10 km) is responsible for fault weakening, with cataclasis and fluid infiltration creating nucleation sites for neomineralization on displacement surfaces during continued faulting. The role of newly grown, ultrathin, hydrous clay coatings on displacement surfaces in the San Andreas Fault contrasts with previously proposed scenarios of reworked talc/serpentine phases as an explanation for weak faults and creep behavior at these depths.