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Deformation mechanisms in the San Andreas Fault zone – a comparison between natural and experimentally deformed microstructures

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The San Andreas Fault (SAF) in California marks the boundary between the Pacific plate and the North American plate. The San Andreas Fault Observatory at Depth (SAFOD) is located 9 km northwest of the town of Parkfield, CA and provide an extensive set of samples through the SAF. The SAFOD drill hole encountered different lithologies, including arkosic sediments from the Salinian block (Pacific plate) and claystones and siltstones from the Great Valley block (North American plate). Fault deformation in the area is mainly by a combination of micro-earthquakes and fault creep. Deformation of the borehole casing indicated that the SAFOD drill hole cross cuts two actively deforming strands of the SAF. In order to determine the deformation mechanisms in the actively creeping fault segments, we have studied thin sections obtained from SAFOD phase 3 core material using optical and electron microscopy, and we have compared these natural SAFOD microstructures with microstructures developed in simulated fault gouges deformed in laboratory shear experiments.

The phase 3 core material is divided in three different core intervals consisting of different lithologies. Core interval 1 consists of mildly deformed Salinian rocks that show evidence of cataclasis, pressure solution and reaction of feldspar to form phyllosilicates, all common processes in upper crustal rocks. Most of Core interval 3 (Great Valley) is also only mildly deformed and very similar to Core interval 1. Bedding and some sedimentary features are still visible, together with limited evidence for cataclasis and pressure solution, and reaction of feldspar to form phyllosilicates. However, in between the relatively undeformed rocks, Core interval 3 encountered a zone of foliated fault gouge, consisting mostly of phyllosilicates. This zone is correlated with one of the zones of localized deformation of the borehole casing, i.e. with an actively deforming strand of the SAF. The fault gouge zone shows a strong, chaotic foliation, lens-like features, micro-folding and occasional indicators of cataclasis and pressure solution in porphyroclasts. Within Core interval 3, deformation appears to be strongly localized in this foliated fault gouge, while rocks outside the gouge have experienced far less deformation. Also Core interval 2 contains a foliated fault gouge which is correlated to a zone of borehole casing deformation. The gouge looks almost identical to the foliated fault gouge in Core interval 3. However, in this core interval the rocks surrounding the actively creeping zone show ample evidence for micro-folding, foliation development, development of anastomosing shear bands, gouge formation, veining, and reworking of earlier formed microstructures. Further, evidence is widespread for cataclasis, pressure solution and reaction of feldspar to form phyllosilicates. Deformation in this core interval is not purely localized in the phyllosilicate-rich, foliated fault gouge, like in Core interval 3, but clearly affects the surrounding rocks as well.

The microstructures of the actively creeping zones are very similar, but the surrounding lithologies are different. This difference in lithology probably causes the difference in deformation behaviour between core intervals 2 and 3. Comparison of the SAF microstructures with microstructures obtained from various experimentally deformed phyllosilicate-rich fault gouges shows many similarities. The similarities include microstructures indicating pressure solution, alteration, foliation development, cataclasis, plastic deformation and lens formation. We therefore infer that the deformation mechanisms identified in the experimental samples are the same as the mechanisms controlling deformation in the actively deforming strands of the SAF, pointing to slip on phyllosilicate foliation accommodated by plastic deformation of intervening clasts, cataclasis and occasionally mass transfer processes.