Comminution and Mineralization of Subsidiary Faults in the Damage Zone of the San Andreas Fault at SAFOD

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Spot core from the San Andreas Fault Observatory at Depth (SAFOD) borehole provides the opportunity to characterize and quantify damage and mineral alteration of siliciclastics within an active, large-displacement plate-boundary fault zone. Deformed arkosic, coarse-grained, pebbly sandstone, and fine-grained sandstone and siltstone retrieved from 2.55 km depth represent the western damaged zone of the San Andreas Fault, approximately 130 m west of the Southwest Deforming Zone (SDZ). The sandstone is cut by numerous subsidiary faults that display extensive evidence of repeating episodes of compaction, shear, dilation, and cementation. The subsidiary faults are grouped into three size classes: 1) small incipient faults, 1 to 2 mm wide, that record early fault development, 2) intermediate-size faults, 2 to 3 mm wide, that show cataclastic grain size reduction and flow, extensive cementation, and alteration of host particles, and 3) large subsidiary faults that have cataclastic zones up to 10 mm wide. The cataclasites contain fractured host-rock particles of quartz, oligoclase, and potassium feldspar, in addition to albite and laumontite produced by syn-deformation alteration reactions. In general, grain shapes and size distributions indicate that potassium feldspar and quartz primarily are deformed through fracture, whereas the oligoclase phase has been fractured and altered to produce albite and laumontite. Five structural domains are distinguished in the subsidiary fault zones: fractured sandstones, brecciated sandstones, microbreccias, microbreccias within distinct shear zones, and principal slip surfaces. We have quantified the particle size distributions of the host rock mineral phases and the volume fraction of the alteration products for these representative structural domains. Overall, the particle sizes are consistent with a power law distribution down to a grain size of at least several microns in diameter. We find that the exponent (fractal dimension) increases with shear strain and volume fraction of laumontite, recording a general transition from constrained comminution to abrasion processes with increasing shear strain. The macroscopic and microscopic structure of the subsidiary faults is consistent with an evolution from the early formation of compacting shear bands while the sandstone was porous, followed by alteration and cementation, and repeated reactivation of the bands by shear and dilation, alteration, and cementation. Later stages of deformation involved localization of slip within the larger bands that contain a very high volume fraction of laumontite.

![Figure 1: Fractal dimension, D, of particle size distribution as a function of increasing shear strain for different host minerals](image)

![Figure 2: Fractal dimension, D, for different volume fractions of laumontite](image)