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The character and evolution of fault rocks from the Phase 3 SAFOD core and potential weakening mechanisms along the San Andreas Fault

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In the region of the SAFOD borehole, the San Andreas Fault (SAF) separates two very different geological terranes referred to here as the Salinian and Great Valley blocks (SB, SVB). Whilst material was not collected from the SB-GVB terrane boundary, the cores preserve a diverse range of fault rocks. Not all of these necessarily formed at the same depth, although the amount of exhumation is likely fairly limited. The distribution of deformation is asymmetric, with a broad (200m wide) intensely deformed region developed in the GVB located NE of the terrane boundary; this includes two narrow zones of active creep that have deformed the borehole casing.

Microstructurally, low strain domains (most of Core 1, significant parts of Core 3) preserve clear protolith structures, with highly localised evidence for classic upper crustal cataclastic brittle faulting processes and associated fluid flow. The GVB in particular shows clear geological evidence for both fluid pressure and differential stress cycling (variable modes of hydrofacture associated with faults) during seismicity. There is also evidence in all minor faults for the operation of solution-precipitation creep.

High strain domains (much of Core 2, parts of Core 3) are characterised by the development of foliated cataclasites and gouge, with variable new growth of fine-grained, interconnected phyllosilicate networks (predominantly smectite-bearing mixed layer clays). Many of the gouges are characterised by the development of S-C fabrics and asymmetric folds. Reworking and reactivation is widespread manifested by: i) the preservation of one or more earlier generations of gouge preserved as clasts; and ii) by the development of later interconnected, polished and striated slip surfaces at low angles or sub-parallel to the foliation. These are coated with thin smectitic phyllosilicate films and are closely associated with the development of lozenge, arrow-head and triangular mineral veins (mostly calcite) precipitated in dilation sites during slip. Outwith of the actively creeping sections, mineral veins (mainly calcite, locally anhydrite) are widespread, with evidence for hydrofracturing events prior to, during and after local gouge-forming deformation episodes. Disseminated pyrite mineralisation is widespread and locally produces highly indurated sections of black, hard gouge. The gouges in the active creeping segments are different in three important respects: 1) mineral veins only occur as (or within) clasts; 2) pyrite mineralisation is limited; and 3) they carry numerous serpentinite clasts, some quite large (metre scale). The actively creeping gouges are also characterised by the most intense development of smectitic phyllosilicates.

The SAFOD core fault rocks highlight the fundamental role played by fluid-rock interactions in upper crustal fault zones. There is clear evidence for the development of high pore fluid pressures (hydrofracture development), reaction weakening (phyllosilicate growth following cataclasis) and geometric weakening due to the development of weak interconnected layers (foliations, polished striated slip surfaces). There are also very significant similarities between the fault rocks seen here and those preserved along other deeply exhumed weak faults elsewhere in the world.