The Abstract

Inversions of coseismic slip on continental slip faults show that maximum slip occurs at depths of 3-5 km, and above these depths fault slip decreases to ~50% of its maxima. Hypotheses to explain this slip deficit, and its long-term recovery, focus on the processes within the fault zone, or the maturity of the fault, both of which may promote distributed or aseismic slip. We examine fault-related rocks from the upper parts of the active San Andreas and ancient San Gabriel faults, southern California, to examine the structure and geochemistry of the shallow portions of two mature faults. The steep-dipping San Gabriel Fault (SGF) was sampled via a steeply inclined borehole to a depth of 400 m, and the San Andreas Fault (SAF) was sampled by seven northeast plunging boreholes to a depth of 250 m with ~95% core recovery rate of relatively intact core. Due to post faulting uplift of the San Gabriel Mountains, fault-related rocks of the SGF could have formed as deep as ~4 km depth. Petrographic, mineralogic, whole-rock geochemical analyses, and X-Ray fluorescence mapping of core and thin sections reveals evidence for abundant and repeated syntectonic alteration, shearing and brecciation of fractured damage zone rocks, formation of foliated cataclasites, pseudotachylites, and clay- and chlorite-rich shear zones. We use core samples from the San Andreas Fault, we imaged thin sections with high resolution imaging methods.

What we have done

For the San Andreas fault, we have recompiled the geotechnical log into a structural - alteration log. For samples from the San Andreas Fault, we imaged thin sections with high resolution imaging methods.

The Results

Core

From both sites, core is remarkably intact and recovery rates are 90-95%

Protopilits exhibit intact gneissic lithologies with well expressed foliations and mineralogy

Damage zones are altered to chlorite-poorer to coesite-carbonatite rich foliated zones, with high degree of fractures, veins, and evidence for shearing.

Fault cores consist of fine-grained cataclase, chlorite-rich foliated zones, shered veins, and healed fractures.

X-Ray Fluorescence Microscopy Mapping

enable us to map at high resolution the distribution of elements in different parts of the fault zone. We focus on key elements Fe, Mn, K, Ca, Cr, Ni, which can be used to map fluid movement (Fe, for example, via Fe oxide transport). We use concentration by fluid assisted removal Ti and Cr or likely concentrated by removal of soluble components. Our maps indicate significant elemental additions to sheared zones (Fe), concentration of immobile elements (Cr, Ti), and transport of soluble components K and Ca. This work is done at the SSRRL lab, Stanford, and these samples are from the San Andreas Fault.

Whole-rock X-Ray Fluorescence Geochemistry

is a traditional way to determine geochemical variations on cm-scale samples across the fault zones. Here we show that damaged and sheared rocks exhibit significant increases in Fe, Ca, and Li.

What we think these data mean

The work of Kaitlyn Crouch and Caroline Studicky show that rather than consisting of 'incohesive gouge' these fault-related rocks are well petroclastic and sheared. These rocks exhibit significant evidence for interweaving iron and space of aseismic slip, chaotic sheared, brittle deformation, shearing of layer silicates, vein formation, hydrothermal alteration, and fluid migration in and around the fault zones. Based on our previous work, these rocks have significantly lower elastic properties, and thus the fault zone consists of low-velocity materials, and the rocks support a model of development of seismic slip produced rocks during earthquakes, and alteration and likely non seismic slip deformation.

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The Geology and Setting of our samples

We use core samples from the San Andreas and San Gabriel faults. These core rocks are from geotechnical boreholes that transect these two faults. Samples across the San Andreas Fault are from depths of up to 300 m, and the SanGabriel Fault samples are from depth of ~400 m. Due to uplift history of the area these samples may represent variations of depth of ~400 m, and the SanGabriel Fault samples are from depth of ~400 m. Due to uplift history of the area these samples may represent samples of the upper 2-4 km of major strike-slip faults. We hypothesize that mineralogical transformations, fluid-rock interactions, and mechanisms that support seismic and aseismic slip occur in this zone, and that with appropriate sampling, we can tease evidence for these processes from the samples.