Processes that control the strength of faults and the dynamics of earthquakes

Workshop Date: September 10, 2016
Conveners: David Goldsby, Whitney Behr, Greg Hirth, Eric Dunham

Abstract: The goal of the 2016 SCEC Fault Dynamics Workshop was to take stock of where the fault mechanics community stands on understanding the microphysical processes associated with dynamic weakening and fault strength, drive discussion as to how these new constraints can improve our understanding of the earthquake rupture process, and identify areas of future exploration. The workshop had ~120 attendees from a wide range of disciplines and career stages. There were three sessions, one on the mechanisms of dynamic weakening, one on spatial variations in fault resistance, and one on the evolution of the slip zone during an earthquake. The workshop emphasized the power of combining experiments, seismic data, field observations and models in each session.

Intellectual Merit:

Our understanding of processes that lead to dramatic frictional weakening during rapid sliding has improved significantly over the last decade, and SCEC played a major role in stimulating this research. Our workshop took stock of where the community stands on understanding the microphysical processes associated with dynamic weakening, as well as a discussion of how these new constraints on dynamic weakening can improve understanding of the earthquake rupture process and the interpretation of earthquake physics based on seismic observations. The seismic cycle is largely controlled by a balance between the rate at which a fault is loaded and the mechanical properties of the fault. Thus, it is important to understand how fault resistance depends on variables such as normal stress, temperature, and slip rate. High-velocity friction experiments and geophysical observations suggest that mature faults weaken dramatically once a fault reaches a typical seismic slip rate. Furthermore, dynamic rupture models show that coseismic weakening dramatically alters how an individual earthquake propagates and how different faults couple in an earthquake cycle model. However, while many coseismic weakening mechanisms have been proposed, it is still unclear which mechanisms are most important or how the efficiency of weakening varies within the seismogenic zone. Addressing these issues is hindered by the limitations of current high-velocity friction apparatus, which cannot attain normal stresses more than a few tens of MPa and are rarely able to confine pore fluids. These limitations mean that serious progress requires a combination of experimental and theoretical approaches, with careful modeling needed to convincingly isolate a specific weakening mechanism in an experiment. Many challenges remain. Even when models can accurately fit experiments, the uncertainties associated with extrapolating from laboratory conditions to those typical in the seismogenic zone mean that tighter constraints on coseismic weakening require stronger links with field observations. Recent studies have identified several new indicators for seismic slip, but it is still unclear how to combine these observations with existing models for
coseismic weakening. In addition, little progress has been made linking experimental and theoretical work on dynamic weakening with seismic data. Finally, current models typically assume uniform properties and smooth faults, leaving large gaps in our understanding of how roughness influences fault resistance during seismic slip and how spatial variations in fault resistance control the lateral and depth extent of large earthquakes.

Despite the fact that understanding the evolution of fault resistance during an earthquake forms a significant fraction of the SCEC research priorities, it had been over six years since the last SCEC workshop focused on this topic. Our workshop reviewed significant advances since 2009, of which there have been many, discussed how these advances are being included into earthquake rupture models, and identified new challenges for the future.

**Broader Impacts:**

Due to the overwhelming interest in our workshop this year, Tran Hunyh of SCEC devised a plan whereby we could admit 140 applicants instead of 90, of which ~120 were in attendance. The conveners, recognizing the importance of educating the next generation of scientists, made every effort to admit as many grad students, post-docs and other early career scientists as possible to the workshop, and preference was given to female and underrepresented applicants when possible. Numerous applicants from governmental agencies, consulting firms, and other companies were also in attendance.

**Specific Workshop Highlights**

The Fault Dynamics workshop was held on September 10, 2016 at the Hilton in Palm Springs just prior to the Annual SCEC meeting. A diverse group of ~120 geoscientists ranging from graduate students to retired faculty, met from 9am to 5pm to discuss the processes that control the strength of faults and the dynamics of earthquakes. The purpose of the workshop was to take stock of where the community stands on understanding the microphysical processes associated with dynamic weakening and drive discussion as to how these new constraints can improve our understanding of the earthquake rupture process. There were three sessions in total:

- Session 1: Mechanisms of coseismic weakening.
- Session 2: Spatial Variations in fault resistance.
- Session 3: Evolution of the slip zone during an earthquake.

The workshop emphasized the power of combining experiments, seismic data, field observations and models in each session. The agenda and contributed PDFs of workshop presentations are available here:

https://www.scec.org/workshops/2016/faults
Session 1 Highlights:

Session 1 demonstrated that mechanisms of coseismic weakening are increasingly well documented in experiments. The mechanisms include flash heating, thermal pressurization, melt lubrication, silica gel lubrication, nano-powder lubrication, and grain-size sensitive (superplastic) flow.

Questions for future work that arose out of workshop discussion:
   a. How do we distinguish among these different mechanisms using both field and seismic observations?
   b. At what conditions does each mechanism operate and are there important feedbacks among them?
   c. How can we parameterize them for use in earthquake rupture models?

Session 2 Highlights:

A primary highlight of Session 2 was the recognition that fault strength depends on fault roughness and its spatial dimension.

Questions for future work that arose out of workshop discussion:
   a. How do we capture the evolution of fault roughness in earthquake cycle models?
   b. How do we modify our constitutive relationships to account for dependence of fault resistance on spatial scale?

Session 3 Highlights:

Session 3 focused on new proxies for recognizing frictional heating on faults. The proxies discussed included pseudotachylite, clay alteration, decarbonation reactions, hematite to magnetite transition, and thermal maturity of organic matter.

Questions for future work that arose out of workshop discussion:
   a. Can we improve the calibrations for these proxies in order to estimate the degree of temperature rise with greater precision?
   b. What do spatial variations (down-dip, along-strike, and relative to the primary slip surface) in temperature rise tell us about the earthquake process?