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Fault Lubrication and Earthquake Propagation in Thermally Unstable Rocks

Nicola De Paola (1), Takehiro Hirose (2), Tom Mitchell (3), Giulio Di Toro (4,5), Cecilia Viti (6), and Toshiko Shimamoto (7)

(1) University of Durham, Earth Sciences, Durham, United Kingdom (nicola.de-paola@durham.ac.uk, +44 0191 3342301), (2) Kochi Institute for Core Sample Research, JAMSTEC, Kochi, Japan, (3) Experimental Geophysics Laboratory, Institute for Geology, Mineralogy, and Geophysics Ruhr-University Bochum, D-44780 Bochum, Germany, (4) Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy , (5) Dipartimento di Geoscienze, Università di Padova, Italy., (6) Dipartimento di Scienze della Terra, Universita' degli Studi di Siena, Italy, (7) Department of Earth and Planetary System Science, University of Hiroshima, Japan

During earthquake propagation in thermally unstable rocks, the frictional heat generated can induce thermal reactions which lead to chemical and physical changes in the slip zone. We performed laboratory friction experiments on thermally unstable minerals (gypsum, dolomite and calcite) at about 1 m/s slip velocities, more than 1 m displacements and calculated temperature rise above 500 C degrees. These conditions are typical during the propagation of large earthquakes.

The main findings of our experimental work are:
1) Dramatic fault weakening is characterized by a dynamic frictional strength drop up to 90% of the initial static value in the Byerlee's range.
2) Seismic source parameters, calculated from our experimental results, match those obtained by modelling of seismological data from the 1997 Cofliorito earthquake nucleated in carbonate rocks in Italy (i.e. same rocks used in the friction experiments).

Fault lubrication observed during the experiments is controlled by the superposition of multiple, thermally-activated, slip weakening mechanisms (e.g., flash heating, thermal pressurization and nanoparticle lubrication). The integration of mechanical and CO_2 emission data, temperature rise calculations and XRPD analyses suggests that flash heating is not the main dynamic slip weakening process. This process was likely inhibited very soon ($t < 1s$) for displacements $d < 0.20$ m, when intense grain size reduction by both cataclastic and chemical/thermal processes took place. Conversely, most of the dynamic weakening observed was controlled by thermal pressurization and nanoparticle lubrication processes. The dynamic shear strength of experimental faults was reduced when fluids (CO_2, H_2O) were trapped and pressurized within the slip zone, in accord with the effective normal stress principle. The fluids were not initially present in the slip zone, but were released by decarbonation (dolomite and Mg-rich calcite) and dehydration (gypsum) reactions, both activated by frictional heating during seismic slip. The dynamic weakening effects of nanoparticles (e.g. powder lubrication) are still unclear due to the poorly understood mechanical properties of nanoparticles at high velocities and temperatures, typical of seismic slip.

The experimental results improve our understanding of the controls exerted on the dynamic frictional strength of faults by the coseismic operation of chemical (mineral decomposition) and physical (grain size reduction, fluids release and pressurization) processes. The estimation of this parameter is out of the range of seismological studies, although it controls the magnitude of the stress drop, the seismic fault heat flow and the relative partitioning of the earthquake energy budget, which are all controversial and still debated issues in the scientific community.