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Faults and Earthquakes (Louis Néel Medal Lecture)

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I have been studying fault rocks and fault mechanics for 40 years, trying to understand mechanisms of earthquakes. A basic strategy has been to study fault rocks for understanding deformation and transport processes in fault zones at depths, to reproduce the same processes in laboratory experiments and determine mechanical and transport properties of faults, and to conduct earthquake modeling based on measured properties and compare with natural earthquakes. I will try to give an overview of the progress of fault studies in the last 25 years, emphasizing the importance of such integrated studies. The following four topics will be covered from my own perspectives of fault and earthquake studies. High-velocity frictional properties of faults in relation to earthquake rupture dynamics will be the main focus, but the lecture will cover lithosphere rheology, initiation processes of earthquake-induced landslides, and a basin evolution and pore-pressure development as relevant topics.

[1] *Friction to flow law*

A simple friction to flow law merges strength profiles of lithosphere and velocity-dependency models of faults that have been used widely in the last three decades to characterize the thickness and internal structures of the lithosphere and to model earthquake cycles and earthquake rupture propagations, respectively. The law allows analyzing earthquake generations including frictional, transitional and flow properties at shallow to deep faults across a lithosphere. Analyses shows how strength profile evolve during earthquake cycles. The law can be extended to describe brittle to high-temperature flow properties across a lithosphere, and realistic analysis of earthquake generation and interseismic deformation, including postseismic deformation, will be possible.

[2] *High-velocity weakening of fault and a source of diverse seismic activities*

Extensive studies in the last two decades demonstrated that faults undergo dramatic weakening at seismic slip rates, through mechanisms such as flash heating/bulk heating of gouge, frictional melting, and thermochemical pressurization. It is likely that earthquake nucleation is controlled by rate and state frictional properties at slow slip rates, whereas high-velocity weakening can affect the growth processes of large earthquakes. Combinations of those slow and high-velocity properties can produce very diverse seismic and aseismic fault motions. I will also discuss technical problems in building friction apparatuses to extend the high-velocity friction studies to wet environments and to higher normal stresses and temperatures.

[3] *Catastrophic landslides triggered by earthquakes*

Tsaoling landslide in Taiwan is the largest and well-documented landslide among many landslides triggered by the 1999 Chi-Chi earthquake. The landslide occurred along a very flat bedding surface, and a Newmark analysis using high-velocity frictional properties quantitatively reproduced the initiation and runaway processes of the landslide, elucidating the importance of slip weakening of landslide surface. The method has many applications to earthquake-triggered landslides.

[4] *Basin evolution and pore pressure development*

Pore-pressure distribution in the earth is poorly known at present. Analysis of basin evolution, using measured permeability and storage capacity of all formations of a basin, revealed the sedimentation and fluid flow processes in the last 30 Ma that lead to the development of abnormal pore pressure below about 4 km in depths. Modeling based on measured transport properties will be useful to solve many problems such as fluid flow in the earth, effect of water on earthquake generation, waste isolation, and CCS.