Japan Geoscience Union Meeting 2010
(May 23-28 2010 at Makuhari, Chiba, Japan)

SSS019-18 Room: 303 Time: May 24 12:00-12:15

Subduction-zone seismicity and emerging problems in fault-zone rheology

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A traditional view of velocity weakening as a required property for seismogenic fault motion was challenged for the 1999 Chi-Chi earthquake based on laboratory data indicating velocity strengthening for northern part of Chelungpu fault which displaced even more than the southern part (Tanikawa and Shimamoto (2008, JGR). They proposed that rate-and-state friction controls the earthquake nucleation, whereas intermediate to high-velocity friction dictates the growth processes into a large earthquake. Noda & Lapusta (2009, JPGU meeting) demonstrated by dynamic modeling that such a scenario is indeed possible. This changed my view on subduction-zone seismicity completely and I proposed that the drilling project has to be reorganized with a renewed view (Shimamoto, 2009, Seismol. Soc. Japan Meeting and AGU). I have extended my thoughts down to slow slip regimes and would like propose seven new problems to be addressed. The first 3 tasks and next 4 tasks are related to shallow and deep parts of subduction zones, respectively. We should challenge those tasks in the next few years.
Task 1: High-velocity (HV) friction of faults to evaluate their response to earthquake rupture coming from depths. A megathrust earthquake nucleates at a deeper part for well-coupled plate interface such as Nankai Trough, so HV property needs to be determined to analyze the response of shallow faults or plate interface. In particular, initial peak friction needs to be studied systematically under dry and wet conditions.
Task 2: Friction and fracture experiments to determine velocity dependence of faults and post-failure curve. Deformation of accretionary prism itself must be causing ultra-low-frequency earthquakes in shallow parts. Also, fault zones are still evolving at shallow depths and fracturing experiments are equally important as friction experiments.
Task 3: Reexamination of exhumed accretionary prism such as Shimanto belt with a renewed view that background deformation of accretionary prism itself is overprinted by impulse-like deformation due to rupture propagation from depths. The most important task is to identify major deformation mechanisms in megathrust faults that cannot be reached by drilling even with Chikyu.
Task 4: High-temperature and ultralow effective pressure (Pe) friction experiments to understand slow slip and nonvolcanic tremors in the transitional regime. Recent modeling of slow slip by several groups strongly suggests that Pe is on the order of several MPa in the slow-slip regime. Some fault rocks may retain brittle frictional properties even at high temperatures, but other rocks may not. No data at present under such conditions!
Task 5: Deformation mechanisms along megathrust faults, particularly evaluation of the significance of pressure solution. Pressure solution is likely to be important to produce flow deformation in metamorphic schists. But this process exhibit velocity strengthening when fully operational and cannot lead to earthquake nucleation. But megathrust earthquake still can occur if there is a nucleation site, say at the base of megathrust. Task 3 will provide a clue to this problem.
Task 6: Studies on hydrofractures, permeability and fracture seal in metamorphic environments which are needed to analyze pore-pressure (Pp) evolution in subduction zones. How unusually high Pp can be maintained in slow slip regime is a difficult but an exciting problem. Pp may be the most important factor in delineating the megathrust and slow-slip regimes.
Task 7: Dynamic analysis of slow slip and megathrust earthquake cycles using realistic fault

properties are needed to understand how a megathrust earthquake initiates. Recent modeling of Matsuzawa et al. (2009, JpGU and AGU) brought about changes in frequency of slow slip prior to a megathrust earthquake. N. Lapusta and H. Noda have developed a fully dynamic software incorporating realistic fault properties and is ideal for such analyses.

Keywords: fault rheology, fault constitutive property, subduction zone, earthquake,
earthquake mechanism, friction experiment