Preface

This special issue consists of contributions from the International Symposium on Slip and Flow Processes in and below the Seismogenic Region, which was held in Sendai, Japan at November 5 through 8, 2001.

The papers presented in this special issue cover a variety of subjects regarding the processes at some depth corresponding to the base of the seismogenic zone:

1. The geometry of the downward extension of the seismogenic faults in the lower crust
2. Loading process of inland earthquake source faults
3. Rheology of the rocks near the seismogenic region and shear localization
4. Fluids in and below the seismogenic region and their effects on the rheology
5. Faults, fluids and friction
6. Acceleration of slip motion in deep extensions of seismogenic faults.

The symposium was mainly focused on the following working hypothesis that downward extensions of seismogenic faults in the lower crust accommodate the localized shear deformation which accumulates stress on the seismogenic faults before large intraplate earthquakes. This model can explain various phenomena related to the crustal deformation, i.e., preslips, seismicity, distribution of active faults, and stress and strain state in the Japanese Island and will play an important role on the forecasting and prediction of large intraplate earthquakes.

There are several papers that cover deeper structure on a variety of faults in Japan, New Zealand, and US. Most of the studies used active sources (seismic reflection and refraction) to image faults at depth. Others used local and teleseismic earthquakes or a combination of the two or gravity data. The techniques for processing earthquake data include receiver function, array analysis, travel time tomography, and fault zone trapped wave. These results show that some faults, such as the Nagamachi-Rifu Fault, NE Japan, seem to flatten and merge to low-angle detachment in the middle crust. There are several sub-horizontal reflectors in the depth range from 12 to 15 km and high Vp/Vs ratio lower crust below the Nagamachi-Rifu Fault. In these cases, the faults extend below the seismogenic layer and are probably terminated within the middle crust. On the other hand, images from teleseismic receiver functions show that the San Andreas Fault, which is a large scale transform fault, penetrates the entire crust.

New dense GPS networks have been established during the past several years across the active island faults in Japan, and case histories of a number of GPS transects are presented. These studies underscore the importance of a full understanding of earthquake deformation cycle for properly interpreting such results. These dense networks are typically comprised of densely spaced (2–5 km) continuous GPS sites that complement the permanent 1000 GEONET array. Inferred fault slip rates generally agree with the geologically constrained values.

Modeling of the earthquake cycle deformation shows that evolution of the pattern and rate of deformation through the cycle depends on both constitutive laws for unstable fault slip and viscoelastic behavior of the sub-seismogenic lithosphere.

The strength of the crust is understood based on a simple model, which utilizes the friction law of rocks in the shallower part of the crust and plastic flow law in the deeper part. This model assumes that rocks are uniformly deformed in the ductile region. However this model cannot explain the cut-off depth of seismicity in the intraplate environment. Therefore, a question arises of whether the deformation is localized under mid to lower crustal conditions. Natural shear zones suggest that the deformation is localized under these conditions. For example, the Hatagawa Fault Zone, NE Japan, which was formed at the brittle-plastic transition, shows clear shear localization. Several possibilities, such as shear heating and diffusion creep can be considered as a strain localization mechanism. Experimental study is important for understanding the elemental processes and rheological properties of the crust. Regional data such as temperature distribution is also important for understanding the environment of seismogenic zone.

Electromagnetic studies can image fluids in the crust as high conductivity (low resistivity) anomalies and are useful in studying the fluid distribution and the fluid connectivity in the extension of the intraplate fault. The resistivity structure across the Itoigawa-Shizuoka tectonic line was studied, which is one of the most active intraplate faults in Japan. A mid-crustal conductor was found underneath the deformation zone. The conductor implies distribution of connected fluids, which are hosted by porosity-enhanced rocks in shear zones. Current seismicity clusters in the resistive regions near the resistive-conductive block boundary. This suggests the triggering the micro-earthquakes by fluid migration into less conductive (less permeable) crust. A deep crustal conductor was also found at a possible deep extension of the fault.

Materials science and field-based structural approaches explore microscale to macroscale fluid distribution and effects of fluids on mechanical behaviour of rocks at elevated temperatures. The results of experimental studies revealed the effects of fluid pressures on the evolution of permeability in marble during progressive deformation. Field-based structural, microstructural and microchemical approaches in ancient exhumed shear zones were used to illustrate coupling between deformation processes, fluid pressures and chemical fluid-rock reaction in both high fluid flux shear systems and low fluid flux shear zones.

These studies raised a number of questions about the distribution, timing, origins of fluids and controls on fluid fluxes in faults and shear zones in deep crustal settings. For example, what geodynamic settings promote involvement of fluids in earthquake nucleation? What conditions favour the tapping of deep crustal fluid sources and/or the involvement of shallower crustal fluid reservoirs? What controls the relative importance of (1) advective flow and related fluid pressure build-up below low permeability flow barriers (high fluid flux regimes), versus (2) build-up of high pore fluid factors by compactional processes (low fluid flux regimes), in controlling earthquake nucleation and recurrence? Significant advances in understanding the generation, migration and distribution of fluids in the mid- to deep crust, and the impact of fluids on deformation processes will be dependent on integrating multidisciplinary approaches.

Effects of fluid on deformation in a fault zone, physical mechanisms of stable and unstable transition in fault constitutive behavior, and fault zone structure were discussed .There are several effects of fluid on deformation and earthquake generation processes. Chemical processes such as pressure solution creep result in evolution of fluid pressure and rock properties during earthquake cycles. During dynamic rupture, pressurization of pore-fluid acts as a dynamic weakening mechanism. Pore fluid pressure and its evolution controls generation processes and the recurrence of earthquakes. It was theoretically demonstrated that the ratio of pore fluid pressure to lithostatic pressure is a fundamental parameter governing earthquake scaling laws. Physical properties of the fault zone such as permeability and stress state are important factors for the model calculation.

Acceleration of aseismic slip in deeper extensions of seismogenic faults prior to large earthquakes is a key process. The aseismic slip in the lower crust could be generated by several mechanisms of shear localization, including yield of an elastic-viscous material, softening of an elastic-viscous material and so on.

What remains to be done through working together is to understand the physical mechanisms of rheological laws: experimental studies examining time and stress dependent parameters, and analysis of material structure in the fault zone. To validate the models, we need to carry out long term monitoring of the evolution of fluids and deformation at depths.

The guest editors regret that several important papers were not included in this special issue, simply because of tight deadline for rapid publication of the special issue. We also hope this special issue will be a milestone of multi-disciplinary approaches for earthquake generation study.

We would like to thank the following persons for their help in organizing and summarizing the sessions; Akira Hasegawa, Lupei Zhu, Wayne Thatcher, Takashi Sagiya, Norio Shigematsu, John Wheeler, Alan G. Jones, Stephen Cox, Bunichiro Shibazaki, Jean-Pierre Gratier, Steve A. Miller, Bruce Hobbs and Hidemi Tanaka. Finally, we would like to express our gratitude to Ministry of Education, Culture, Sports, Sciences and Technology (MEXT) for the sponsorship and Prof. Yoshimori Honkura for continuous encouragements for the publication.

Guest Editors: Hisao Ito
Gregory Beroza
Koichiro Fujimoto
Yasuo Ogawa