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U002-01 Room:IC Time:May 25 08:30-08:54

New research for earthquake, tsunami and mitigation -Observation, simulation research and disaster measure in Japan-

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Research groups of Seismic linkage around the Nankai trough sesismogenic zone

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Abstract
Japan is known as one of the highest seismicity country in the world. Megathrust earthquakes over M8 and large tsunamis around the Nankai trough southwestern Japan have occurred with the interval of 100-200 years, so these damages are very severe problems in Japan. Therefore, the understanding of the seismic linkage around the Nankai trough seismogenic zone is the very urgent problem which confront us. The past earthquakes occurred in 1944/1946, 1854, 1707, 1605, 1498, and 1361 etc. with strong motions and large tsunamis. In each earthquakes, recurrence patterns and scales are quite difference. For these disaster mitigations against the next megathrust earthquakes and tsunamis, integration of observational researches, simulation researches and disaster measures are quite important and significant in Japan.

As observational researches, we are carrying out structural surveys, seismicity observations to understand crustal activities. In simulation researches, we are studying historical tsunami events, crustal deformations, and developing simulation method/models. Finally, we have to estimate precise seismic hazards and tsunami hazards and make practical proposals of disaster measures. Furthermore, to improve not only early warning system but also understanding of seismic linkage, the real time monitoring system of seismogenic zone using multi kinds of sensors is quite useful to improve simulation models, early warning systems for earthquakes and tsunamis.

Therefore, the megathrust earthquake research projects such as observational researches, simulation researches, disaster mitigation researches and real time monitoring system developments are starting as MEXT projects.

The details of projects are as follows,

1) Observational researches: Seismic surveys using MSC/OBS and seismicity observation

2) Simulation researches: Studies of historical tsunami events by core sample analyses, crustal deformations by precise analyses, developments of simulation methods and recurrence cycle simulation models with data assimilations.

3) Disaster mitigation researches: Simulation of precise hazards and making proposals of disaster measures under discussions with people of local governments, lifeline companies and researchers etc.

4) Real time monitoring researches: Real time monitoring systems (DONET/DONET2) are developing and deploying around the Nankai trough seismogenic zones.

5) New simulation research project for more precise and complex simulations for earthquakes, tsunamis and disaster measures using the peta flops computer

We will talk about these projects including updates.

Keywords: Nankai trough, Subduction zone earthquake, Seismic linkage, Disaster mitigation

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U002-02 Room:IC Time:May 25 08:54-09:18

A innovative new project "KANAME": New perspective of great subduction-zone earthquakes from the super deep drilling

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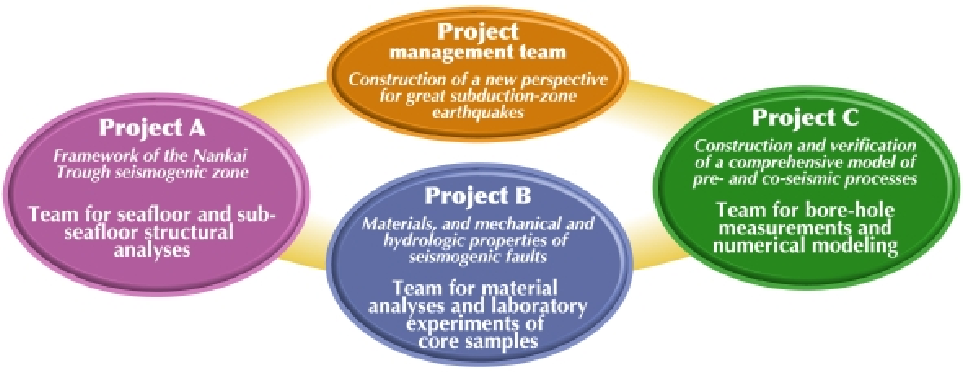
In the past, giant subduction-zone earthquakes and their accompanying tsunamis have caused significant damage, and it is our earnest desire to scientifically elucidate how they occur. We are the first to directly study seismogenic faults along a subduction zone at the Nankai Trough. Great earthquakes and tsunamis have repeatedly occurred at the Nankai Trough, and more are predicted at this site in the near future. Super-deep drilling by the drilling vessel "Chikyu" will enable us to directly sample seismogenic faults as well as conduct analyses, experiments, and in situ borehole measurements. These efforts should significantly improve our understanding of pre- and co-seismic processes of great subduction-zone earthquakes.

Our scientific objective is to significantly improve the understanding of pre- and co-seismic processes of great subduction-zone earthquakes by directly sampling seismogenic faults and conducting analyses, experiments, and in situ bore-hole measurements at the Nankai Trough region, which is a site where great subduction-zone earthquakes have repeatedly occurred and are expected to occur in the near future.?To realize our goal, our strategy consists of the following three schemes: (1) understanding overall framework of the Nankai Trough seismogenic zone, (2) revealing materials, and mechanical and hydrologic properties of seismogenic faults, and (3) construction and verification of a comprehensive model for pre- and co-seismic processes. We have organized three research groups dedicated to these three schemes, each of which further consists of two sub-groups tackling two complementary tasks.



Keywords: earthquake, subduction, Nankai Trugh, tsunami, trench, accretionary prism

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U002-03 Room:IC Time:May 25 09:18-09:42

Variability of Great Earthquakes in the World's Subduction Zones Revealed from Paleo-seismolgy

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Paleoseismological studies conducted since the 2004 Indian Ocean tsunami revealed that a giant earthquake similar to the Sumatra-Andaman earthquake (M 9.1) occurred several hundred years ago. Studies of tsunami deposits made in Sumatra Island (Monecke et al., 2008), Thai coast (Jankaew et al., 2008), Andaman Island (Malik et al., 2011) and Indian Coast (Rajendran et al., 2011) show evidence of past tsunamis. Coseismic coastal uplifts were inferred from marine terraces in Myanmar (Aung et al., 2008) or microatolls in Andaman Island (Kayanne et al., in preparation) and Sumatra Island (Sieh et al., 2009). Evidence of past coseismic subsidence was found in southern Andaman Island (Malik et al., 2011).

These paleoseismological studies also indicate variability of past earthquakes. The date of penultimate earthquake was estimated at around AD 1300 to 1450 in Thailand, AD 1290-1400 in Sumatra, but much later, post AD 1600 in Andaman Island. These variable dates may indicate that the last earthquake was not exactly the same type as the 2004 Sumatra-Andaman earthquake.

Such variability in size of past earthquakes or supercycle of earthquake recurrence (Sieh et al., 2008) was also found in subduction zones around the Pacific Ocean (Satake and Atwater, 2008). In Kuril subduction zone, unusually large earthquakes occurred with approximately 500 years but variable intervals (Nanayama et al., 2003; Sawai et al., 2009), with the last earthquake in the 17th century. Historical tsunami heights or coastal changes from the large recurrent earthquakes along Nankai trough also show variability. In southern Chile, the 1960 earthquake was much larger than the previously recorded earthquakes in historical literature in 1837 and 1737, and similar to the 1575 earthquake (Cisernas et al., 2005). In Cascadia subduction zone of North America, giant earthquakes similar to the 1700 earthquake seems to have occurred at approximately 500 years interval, but the detailed studies show that recurrence interval and size of past earthquakes also seem to be variable (Atwater et al., 2005).

Variable recurrence patterns, revealed from paleoseismological data for much longer time range than historical records, indicate a difficulty in long-term forecast for future earthquakes. While most long-term forecasts of next earthquakes and its size assume recurrence of characteristic earthquakes, they may need to consider the variability observed in other subduction zones. This is more important in a few subduction zones, such as the Kuril subduction zone off Hokkaido or the Sunda subduction zone off Sumatra, because they might have entered in an active period of great earthquakes.

Keywords: Subduction zones, earthquake, tsunami, paleoseismology, recurrence, long-term forecast

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U002-04 Room:IC Time:May 25 09:42-10:06

Geometrical Constraints on World Deep Tremor

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Deep tectonic tremor has been discovered in many places in the world, but little was known about control factors of the activity. A standardized analysis of tremor in four tremor zones enables to compare regional characteristics of tremor activity. Here I show that tremor duration and sensitivity to tidal stress are controlled by the width tremor zone in the subduction direction. Local structures such as striations may act as the size yielding the variety of tremor activity.

The study areas are the Nankai subduction zone (SZ) in southwestern Japan, the Cascadia SZ in western Canada and USA, the Jalisco-Colima-Michoacan SZ in northern Mexico, and the Chile triple junction. The data are from Hi-net of NIED Japan (Nankai), the Canadian National Data Centre, POLARIS broadband seismic stations, University of Washington, University of Oregon, UC Berkeley, Plate Boundary Observatory and USArray of EarthScope Program (Cascadia), Mapping the Riviera Subduction Zone Project (Mexico), and Chile Ridge Subduction Project (Chile).

A modified version of envelope correlation method was applied to these data. This method divides continuous records of velocity envelope into a set of half overlapping 300 s time windows, detects a seismic source in each window, and determines the source locations as well as the event duration as a half value width of the stacked envelope. Although the method does not automatically distinguish tremor sources from ordinary earthquakes, by extracting events longer than 10 s, we can eliminate most of ordinary earthquakes.

In western Shikoku, the western end of the Nankai tremor zone, the duration is anti-correlated with the sensitivity to tidal stress, which is also observed in other SZs. The sensitivity to tidal stress measured by the Fourier amplitude at semi-diurnal lunar period for delta-function sequences, each of which corresponds to the tremor origin time, shows similar negative correlation. Moreover, we observe regional difference of typical duration: Cascadia tremor is the longest and Mexican tremor is the shortest. This duration correlates with the width of tremor zone in the subduction direction. The width is up to about 65, 45, 40, and 30 km for Cascadia, Nankai, Chile, and Mexico. In the very narrow (< 20 km) tremor zone near the northern end of Mexico, tremor is very sensitive to tidal stress. On the other hand, long-distance migration of tremor sources is often observed for very long tremor in the wide tremor zone of Cascadia SZ, which is consistent with the observation in western Shikoku.

The observation in these SZs suggests the idea that the geometry of tremor zone constrains tremor behavior. The characteristic size of tremor zone has been introduced to tremor models that consider random processes, where the size corresponds to the change point in the scaling law of slow earthquakes, from short diffusive migration to long migration at a constant velocity. Below the width extent in the subduction direction, there may be diffrent kind of characteristic size, such as the width of striations identified in western Shikoku and also visible. In western Shikoku fast (~10 m/s) tremor migration along a narrow striation has been detected, where the typical duration is very short.

A dense structural survey illustrated a mechanism to produce tremor zone, which is formed in the wedge mantle near the Mohorovicic discontinuity by water dehydrated from the subducting slab. If such a mechanism is working everywhere, the total amount of water transported by plate subduction, or simply the amount of subducted materials may control the size of tremor zone and tremor behavior. A long subduction history is also reflected in large accretionary prism along the trench. Therefore, it must not just coincidence that the SZs with large accretionary prism like Cascadia, Nankai, and Chile have thick tremor zones and megathrust earthquakes as large as magnitude 9.

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U002-05 Room:IC Time:May 25 10:06-10:30

Fluid-rich faults and updip slip propagation during great earthquakes in the Nankai and Sumatra subduction zones

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Seismic reflection data sets from two thickly-sedimented subduction zones, the Nankai Trough and the Sumatra subduction zones, reveal shallow fault systems that extend from the seismogenic zone updip close to the seafloor. Based on rupture models, some of these faults likely slipped during recent great earthquakes. Common to both data sets are high-amplitude fault-plane seismic reflections that have a reversed polarity relative to the seafloor and are inferred to be caused by relatively low-velocity, high-porosity within the fault zone. These are inferred to be weak faults conducive to slip during great earthquakes.

In the Nankai Trough, high-amplitude fault-plane reflections from the plate boundary megathrust can be traced downdip to ~ 10 km below seafloor in a 3D seismic reflection data volume acquired in 2006 across the Kumano Basin in the vicinity of the Integrated Ocean Drilling Program NanTroSEIZE drilling area. We attribute these anomalously high-amplitude fault-plane reflections to underthrusting of relatively high-porosity, fluid-rich sediment. The area where the fault has high-amplitude reflections corresponds to a region of anomalously shallow updip slip propagation during the 1944 Tonankai M8.0 earthquake. This fault may be weakened by the presence of fluids thus enabling unusually shallow updip slip propagation.

Two-dimensional seismic reflection data from Sumatra that were acquired in 2008 reveal the outermost accretionary wedge structure near the deformation front across the slip region of the 2004 M 9.2 earthquake. Here the outer wedge has multiple examples of high-amplitude, reversed-polarity reflections that are similar to Nankai examples. These thrusts extend upwards from the plate-boundary thrust through much of the upper plate and may have slipped during the 2004 event. In this presentation I will compare fault characteristics of both margins and their slip behaviors during great earthquakes.

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U002-06 Room:IC Time:May 25 10:45-11:09

Alternating periods of high and low activity along the megasplay fault in the Nankai Trough

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Data and results from Stage 1 and 2 operations of the ongoing Integrated Ocean Drilling Program (IODP) Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) ? a complex ocean drilling project that eventually attempts to drill, sample, and instrument the seismogenic zone to yield insights into processes responsible for earthquakes and tsunamis offshore the Kii Peninsula, southwest Japan ? characterize the shallow portion of the Nankai Through subduction zone along a transect from the Kumano forearc basin, the shallow megasplay fault zone, the frontal prism to the subduction inputs of the Shikoku Basin. This provides an extensive base for evaluating both long-term and short-term tectonic processes controlling evolution and current state of this subduction margin, as it relates to the present-day earthquake activity.

Here we present result from 3D reflection seismic data interpretation and IODP drilling and coring of slope-apron and slope-basin stratigraphic successions in the shallow megasplay fault zone area to document the tectono-stratigraphic development of the Quaternary Nankai accretionary wedge, the origin and evolution of the margin-dominating megasplay fault system and its effect on sedimentation pattern, seafloor deformation and sediment remobilization.

Three lithostratigraphic subunits are identified within the stratigraphic succession deposited in a slope basin in the front of the advancing splay fault over the last ˜ 2Myrs and several intercalated intervals comprise evidence for significant sediment remobilization periods which are in phase with enhanced activity along the megasplay fault and underlying growing anticline structures. At the tip of the megasplay fault, we document the growth of the fault and its interaction with slope sediments. Dating and collected geological data at drill Sites C0004 and C0008, where the slope sediments are overridden by the hanging wall, indicate that the splay fault initiated 1.95 Ma in the lower part of the prism as an out-of-sequence thrust. After an initial phase of high activity, the movement along the fault slowed down, but uplift and reactivation of the fault resumed about 1.55 Ma.

A remarkable lithological transition between a sandy turbidite sequence (subunit Ib) below and ash-bearing hemipelagites intercalated with mass-transport deposits (subunit Ia) above, was recovered at Site C0018 during the most recent IODP Exp 333 (Dec 2010 - Jan 2011). Within the underlying turbidite sequence, seismic data reveal that a series of small channels oriented perpendicular to the paleoslope was cut within a very short time period (˜1.55-1.24 Ma) and were filled within the next seismically-resolvable time step. Turbidite deposition ceased about 1 Ma, documenting a prominent change in sediment delivery and routing pattern in the study area. This correlates to a significant shift in the sediment depocentre within the Kumano Basin following ˜300 kyr of extensive landward tilting of the outer Kumano basin sediments, which has been interpreted to represent a major period of motion along the megasplay that formed the modern fault geometry.

Seafloor deformation by slumping is a dominant ongoing process on the slope in the shallow megasplay fault zone area, with numerous surficial slump scars evident in the seafloor topography. A sub-recent, presumably seismically-triggered mass-transport deposit has been recovered within the first two meter subbottom depth at Site C0018. This, as well as the occurrence of a thin mud-breccia layer in the shallow-most part of Site C0004, for which radioisotope dating indicates a deposition time consistent with the 1944 Tonakai earthquake, indicates that slope sediments not only provide long-term records of the structural evolution of the megasplay fault system but also may record the recent seismic activity of large megathrust events.

Keywords: IODP, NanTroSEIZE, Nankai Trough, Megasply fault zone, tectono-stratigraphic evolution, slope basin sediments

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U002-07 Room:IC Time:May 25 11:09-11:33

Preliminary results from IODP Expedition 333: Subduction inputs 2 and heat flow

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Expedition 333 was conducted as a part of the NanTroSEIZE project. Two input sites on the Shikoku Basin: C0011 and C0012 were cored and measure temperature in the interval that was not done during Expedition 322. Sites C0011 is located on the north-west flank of Kashinosaki Knoll, and C0012 is atop the Knoll. A total thickness of 380 m sediment was cored at Site C0011. The late Pleistocene ? late Miocene Shikoku Basin facies and an underlain volcaniclastic sand facies were recovered. Shipboard measurements demonstrate drastic physical property changes occurred within the Shikoku Basin facies which is similar to down-hole changes at sites 1173 and 1177 in the Muroto and Ashizuri input sites, offshore the Shikoku Island. A total thickness of 180 mbsf sediment was cored from the top of Sites C0012. A similar lithology to that of C0011 was recovered. However, the sequence involves a significant hiatus in the early Pleistocen-late Pliocene time. A disturbed structure in the interval of 15-85 mbsf suggests a large-scale slumping event in the north flank of the Knoll in that time. Below the sediment?basement interface around 525 mbsf, Site C0012 was deepened up to 630.5 m in order to characterize basement alteration. Recovered basalt rocks are altered heterogeneously. Such alternations may be an important key to understand a change in mechanical strength distribution within the basement during a subduction process. High quality strata temperature data were obtained during HPCS operation at sites C0011 and C0012. Preliminary estimation reveals the higher temperature gradient at site C0012. Analysis of through sediment and basaltic basement composition, geomechanical experiments and hydrological modeling will provide a complete characterization of incoming sediments and igneous basement prior to their arrival at the subduction front and seismogenic zone.

Keywords: NanTroSEIZE, input site, Heat flow

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U002-08 Room:IC Time:May 25 11:33-11:57

Analysis of forearc morphology along accretionary and erosive margins in the contexxt of Coulomb wedge mechanics

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The taper of outer forearc wedges varies systematically along convergent margins as a function of the rate of accretion vs. erosion. Along margins with slow convergence rates and thick incoming sediment piles (i.e., accretionary margins– Sumatra, Makran, Cascadia, S. Barbados, Nankai), surface slope and taper are generally lower than along margins with rapid convergence rates, thin sediment piles, and extensive slope aprons (i.e., erosional margins– Middle America, S. America, Japan, Tonga). This observation can be explained in the context of non-cohesive critical Coulomb wedge behavior (Dahlen, 1984). For any given surface slope (or basal dip), there are two possible solutions for the critical taper (i.e., the maximum and minimum tapers), or the taper at which a wedge is everywhere at the verge of failure while sliding on a weak basal decollement. Along accretionary margins, trench sediments deform until the minimum taper is attained, the wedge slides at the verge of failure, and the locus of deformation shifts to the subcritical material of the protothrust zone. Along erosive margins where where material is removed from the upper plate preferentially updip along the plate boundary, the taper can exceed the minimum taper because there is no mechanism for maintaining the wedge at the lowest possible taper, and the wedge can slide as long as the taper is at or less than the maximum taper. Given the fact that these margin wedges are typically composed of basement of upper plate or old accreted material, it is unlikely that the greater taper is due to maintenance of minimum taper with a weaker wedge, although the basal friction could be larger. Thus, accretionary prisms and erosional margin wedges have significantly different cross-sectional geometries that relate to adjustments of a critical wedge to fluxes at the boundaries. In cross section, most forearc wedges have convex upward surface slopes. One explanation for this morphology is that arcward increasing strength within the wedge due to lithification and porosity reduction leads to a narrower minimum critical taper. An alternative argument is that the basal dip increases arcward. In such a case, the surface slope must decrease or even reverse direction arcward for a wedge of constant taper. These concepts are developed this presentation with reference to accretionary margins (Kodiak, Sumatra) and erosive convergent margins (Japan, Costa Rica).

Keywords: Coulomb mechanics, accretionary wedge, critical wedge, forearc, taper

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U002-09 Room:IC Time:May 25 11:57-12:21

Subduction-zone rheology: current status and future tasks

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I have re-evaluated Subduction-zone rheology and seismicity and have listed the following 7 major tasks (Shimamoto, 2010, JpGU; Shimamoto, 2010, GRC). This review talk will focus on task 1 and task 4 which will be important with respect to the seismogenic-zone drilling and slow slip, respectively. Task 1: High-velocity (HV) friction of faults to evaluate the response of shallow accretionary prism to earthquake rupture coming from depths. Task 2: Friction and fracture experiments to determine velocity dependence of faults and post-failure curve for understanding low-frequency earthquakes in shallow subduction zones. 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. Task 4: High-temperature and ultralow effective-pressure (Pe) friction experiments to understand slow slip and nonvolcanic low-frequency tremors in the transitional regime. Task 5: Deformation mechanisms along megathrust faults, particularly evaluation of the significance of pressure solution. 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, AGU; 2010, JpGU) brought about changes in frequency of slow slip prior to a megathrust earthquake. Earthquake forecast might become possible by exploring interactions between megathrust and slow slip regimes.

One of the central issues in the Nankai drilling project is to explain the updip limit of seismogenic zone. A fashionable view for the aseismic to seismic transition is the change from velocity weakening at shallow depths to velocity strengthening at the updip limit. Despite nearly 10 years efforts of PennState group, it was not easy to get velocity weakening behavior for clayey fault gouge. I proposed that high-velocity friction is important to study the response of shallow accretionary prism to the megathrust rupture coming from depths (Shimamoto, 2009, AGU). Faulkner at al. (2010, Padova workshop) went one step further; they showed that fault gouge composed of several clay minerals has very low friction without clear peak friction (drained high-velocity experiments) and proposed that the earthquake rupture can propagate through the shallow accretionary prism without much resistance. A new low to high-velocity machine at Institute of Geology, CEA, Beijing was designed to study this problem and has a velocity jump capability up to six orders of magnitude. I would like to summarize the current status on this issue including some new experimental results.

Another issue I will address is fault rheology in the slow slip regime. Recent modeling of slow slip by several groups strongly suggests that Pe is on the order of several MPa or lower in the slow-slip regime. Seismicity has been reported at estimated temperatures even over 500 degrees Celsius. Shimamoto and Noda (2101, AGU) proposed an empirical law linking the rate-and-state fault constitutive law and rate-and-state flow law (Noda and Shimamoto, 2010, GRL). This will be useful for modeling slow slip and low-frequency tremors and will give insight on designing experiments to cover the brittle to fully plastic fault motion using realistic rocks. The law predicts how brittle frictional properties remains to higher-temperature condition with increasing pore pressure.

Keywords: subduction zone, rheology, fault, earthquake