Workshop on Estimation of inelastic deformation and earthquake generation model

Department of Earth and Planetary Science, The University of Tokyo
https://www.s.u-tokyo.ac.jp/en/map/map02.html

Dec. 27
Room No. 710 (7th floor)
13:30-14:10 Takeshi Sagiya (Nagoya Univ.)
Persistent inelastic deformation in northeast Japan: implications for elastic strain budget
14:20-16:00 Sylvain Barbot (Earth Observatory of Singapore, Nanyang Technological University)
From crustal to lithosphere dynamics: new perspectives
Water stratification in the Indian Ocean lithosphere
16:20-17:00 Akemi Noda (National Research Institute for Earth Science and Disaster Resilience)
Physics-based GPS data inversion to estimate three-dimensional elastic and inelastic strain fields
17:00-18:30 Discussion

Dec. 28
Room No. 336 (3rd floor)
10:00-11:30 Sylvain Barbot
The Parkfield tremors reveal slow and fast rupture on the same asperity
Partial rupture of fully locked patches: The role of fault morphology
11:30-13:00 Lunch and discussion
13:00-13:40 Ryosuke Ando (Tokyo Univ.)
Brittle-plastic fault heterogeneity model for slow earthquakes
13:40-14:20 Youichiro Takada (Hokkaido Univ.)
Pre, co, and postseismic deformation of active faults and volcanoes in response to the Tohoku-oki earthquake

Special lectures by Prof. Sylvain Barbot (Earth Observatory of Singapore, Nanyang Technological University)

Title: From Crustal To Lithosphere Dynamics: New Perspectives

Abstract: Crustal dynamics involves the nonlinear interactions of faulting, ductile flow, and fluid migration, complicated by a complex thermal and metamorphic history. The rheological properties (describing how materials deform under stress) of mantle and crustal rocks control many important tectonic processes ranging from continental drift to earthquake triggering, thereby playing a crucial role in the distribution of seismic hazards. Yet the details of their spatial distribution in Earth's interior remain poorly known. We exploit the large stress perturbation incurred by the 2016 earthquake sequence in Kumamoto, Japan to directly image localised and distributed deformation at unprecedented resolution, taking advantage of the dense spatial coverage of the Japanese continuous geodetic network (GEONET), and the rapid acquisitions of the European Sentinel-1A satellite. The earthquakes illuminated distinct regions of low effective viscosity in the lower crust, notably beneath the Mt Aso and Mt Kuju volcanos, surrounded by larger scale variations of viscosity across the back-arc ranging from as low as 5E16 Pa s up to 1E18 Pa s, commensurate with predictions for transient creep of a thermally activated non-linear rheology. This study demonstrates a new potential for geodesy to probe rock rheology in situ across many spatial and temporal scales.

Title: Water stratification in the Indian Ocean lithosphere

Abstract: Water, the most abundant volatile in Earth’s interior, preserves the young surface of our planet by catalysing mantle convection, lubricating plate tectonics and feeding arc volcanism. Since planetary accretion, water has been exchanged between the hydrosphere and the geosphere, but its depth distribution in the mantle remains elusive. Water drastically reduces the strength of olivine and this effect can be exploited to estimate the water content of olivine from the mechanical response of the asthenosphere to stress perturbations such as the ones following large earthquakes. Here, we exploit the sensitivity to water of the strength of olivine, the weakest and most abundant mineral in the upper mantle, and observations of the exceptionally large (moment magnitude 8.6) 2012 Indian Ocean earthquake to constrain the stratification of water content in the upper mantle. Taking into account a wide range of temperature conditions and the transient creep of olivine, we explain the transient deformation in the aftermath of the earthquake that was recorded by continuous geodetic stations along Sumatra as the result of water- and stress-activated creep of olivine. This implies a minimum water content of about 0.01 per cent by weight - or 1,600 H atoms per million Si atoms - in the asthenosphere (the part of the upper mantle below the lithosphere). The earthquake ruptured conjugate faults down to great depths, compatible with dry olivine in the oceanic lithosphere. We attribute the steep rheological contrast to dehydration across the lithosphere-asthenosphere boundary, presumably by buoyant melt migration to form the oceanic crust.

Title: The Parkfield tremors reveal slow and fast rupture on the same asperity

Abstract: The deep extension of the San Andreas Fault is believed to be creeping, but the recent observations of tectonic tremors from these depths indicate a complex deformation style. In particular, an isolated tremor source near Parkfield has been producing a sequence of low-frequency earthquakes that indicates an uncommon mechanism of stress accumulation and release. The tremor pattern regularly oscillated between three and six days from mid-2003 until it was disrupted by the 2004 magnitude 6.0 Parkfield earthquake. After that event, the tremor source ruptured only about every three days, but over the next two years, it gradually returned to its initial alternating recurrence pattern. The mechanism that drives this recurrence pattern is unknown. We use physics-based models to show that the same tremor asperity—the region from which the low-frequency earthquakes radiate—can regularly slip in slow and fast ruptures, naturally resulting in recurrence intervals alternating between three and six days. This unusual slip behavior occurs when the tremor asperity size is close to the critical nucleation size of earthquakes. We also show that changes in pore pressure following the Parkfield earthquake can explain the sudden change and gradual recovery of the recurrence intervals. Our findings suggest a framework for fault deformation in which the same asperity can release tectonic stress through both slow and fast ruptures.

Title: Partial rupture of fully locked patches: The role of fault morphology

Abstract: Assessment of seismic hazard relies on estimates of how large an area of a tectonic fault could potentially rupture in a single earthquake. Vital information for these forecasts includes which areas of a fault are locked and how the fault is segmented. Much research has focused on exploring downdip limits to fault rupture from chemical and thermal boundaries, and along-strike barriers from subducted structural features, yet we regularly see only partial rupture of fully locked fault patches that could have ruptured as a whole in a larger earthquake. Here we draw insight into this conundrum from the 25 April 2015 Mw 7.8 Gorkha (Nepal) earthquake. We invert geodetic data with a structural model of the Main Himalayan thrust in the region of Kathmandu, Nepal, showing that this event was generated by rupture of a décollement bounded on all sides by more steeply dipping ramps. The morphological bounds explain why the event ruptured only a small piece of a large fully locked seismic gap. We then use dynamic earthquake cycle modeling on the same fault geometry to reveal that such events are predicted by the physics. Depending on the earthquake history and the details of rupture dynamics, however, great earthquakes that rupture the entire seismogenic zone are also possible. These insights from Nepal should be applicable to understanding bounds on earthquake size on megathrusts worldwide.