PhD position - **Energy balance, stresses and strains at the seismic cycle scale in the frontal part of subduction margins.**

Université de Lorraine – laboratoire GeoRessources – Nancy, France

Direction

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Context

Subduction zones are known to be the generation site of mega-earthquakes and mega-tsumani (e.g. Heuret and Lallemant, 2011). Seismicity there results from friction between the thrust and subducting plates. It is mainly related to the state of stress on the interface, and to the ability of some portions of the interface to become locked during the seismic cycle (e.g. Perfettini et al., 2010). These locked portions will accumulate elastic strain until they reach their ultimate strength, break and slip over large distances. The mechanical behavior of the interface is described by the "rate and state" model (deDietrich, 1992; Scholz, 1999; Perfettini et al., 2010; Barbot, et al, 2012; Lapusta et al, 2008), which predicts a gradual softening of friction on the fault as it slides over a critical distance at high velocity. Past this distance, the strength of the fault becomes low which favors the propagation of co-seismic rupture. This softening has been shown in high velocity laboratory friction experiments (e.g. Di Torro et al., 2011, Ujiee et al, 2017, Remitti et al, 2012; Ikari et al, 2015), and is largely promoted by the presence of water in undrained conditions. In turn, the elastic energy accumulated prior to seismic rupture is dissipated in the form of slip on faults, heat, seismic waves, and by plasticization of the medium (e.g. Kanamori et al 1997; Kanamori and Brodsky, 2004). The magnitude of earthquakes thus depends on both the capacity of the system to accumulate energy and its capacity to release it. Establishing an energy balance before an earthquake, and understanding how the energy will dissipate in the fractured medium is therefore one of the primary issues in seismology.

The energy contained in an accretionary prism depends on the (i) work of gravity forces, related to the topography and weight of the terrain; (ii) work of frictional forces on the faults, related to their static friction and orientation with respect to the stress state; (iii) deformations in the material, (iv) rupture propagation; (v) radiation of seismic energy; and (vi) work of external forces (e.g. Herbert et al., 2015; Passelègue et al. ,2016; McBeck et al., 2018, 2019; Aben et al., 2019). The energy is balanced if the set of the first five works equals the last (Cooke and Madden, 2014), and recent work suggests that the frictional and rupture propagation forces works dominate the other 3 when constructing accretionary prisms (McBeck et al, 2018) and during seismic ruptures (e.g. Okubo et al, 2019). Therefore, the forces of gravity and internal deformation in the prism are often neglected during energy balances. Yet, during the March 2011 Tohoku earthquake near the trench, the margin front moved 62m seaward (e.g. Sun et al, 2017), tensile rupture observations were made on the seafloor, and satellite faults operated as normal faults (Conin et al., 2012; Cubas et al; 2013) suggesting gravity collapse of the margin front and rupture to the trench. This observation has also been made in the Aluetian subduction zone (Becel et al, 2017). In this specific case, and very close to the margin front, thus a free edge, the plasticity of the upper plate and the gravity effect seem to have played a major role in the intensity of the tsunami (Romano et al, 2014) or even in the propagation of the rupture to the trench. Yet it is not taken into account in energy budgets that focus on the subduction interface (e.g. Brodsky et al, 2020). Furthermore, in the case of Tohoku and Nankai, the subduction interface is not planar (e.g. Chester et al, 2018). Instead, it is thought to be a duplex system with several faults playing at the same time, at least during the interseismic. This geometry questions scientists. One question is whether these same sinuous structures are playing to accommodate the construction of prisms over the long term and to accommodate co-seismic slip, which could change the calculation of energy dissipated during slip (e.g. Kanamori and Brodsky, 2004).

In the Nankai and northern Japan accretionary prisms, the amount of field data, including seismic profiles (margin and subduction interface geometry), seismological measurements, IODP ocean drilling data (fracturing, stress state, rheology, fluid pressures), and laboratory measurements on collected samples allow for quantification of some of the workings of the forces at any given time (e.g. Ismat , 2009; Meade, 2013; Fulton et al., 2013; Savage Coffey et al, 2019; Brodsky et al, 2020; Lin, Conin et al, 2012, Conin et al, AGU abstract 2019) and provide a tremendous opportunity to model the energy stored in the front of these margins prior to a very likely mega earthquake in the case of Nankai (McBeck et al 2020), and prior to the one that occurred at Tohoku in March 2011.

Objectives of the thesis

The first objective is to establish an energy balance at the scale of the Nankai and Northern Japan margins front using 3D hydro-geomechanical numerical modeling, to understand the capacity of the fractured massif to accumulate energy before an earthquake. The modeling will be performed using the 3DEC V7 discrete element modeling software, which has a rate-and-state law for faults, and the ability to simulate gravity collapse at the margin front. The calibration of the parameters (permeability and friction on the interface, geometry of the interface, mechanical properties of the materials, fracture density and equivalent properties, topography, state of stress, ...), will be done from the field data acquired during the IODP missions, and from the bibliography. The results will be compared to energy balances performed by McBeck et al, 2018, and McBeck et al, 2020 from numerical and analog modeling in accretionary prisms, as well as to post-seismic observations performed in the Tohoku area and to the energy balance based on the interface behavior proposed by Brodsky et al, 2020. The second objective is to understand how the rupture propagates along a complex surface, organized in duplex, and if the observed behavior is the same at slow or high speed. For this, the student will perform a series of slow and then fast shear experiments on duplex fault geometries. These experiments will be done on the joint shear machine available in the laboratory. This machine, quite unique in France and refurbished in 2020, now allows to perform friction experiments with controlled velocity variation, fixed normal stress, but also with controlled normal stiffness, which is a real asset to understand the functioning of faults in confined environments. The geometries will be 3D printed with a sand and binder material whose properties we master (e.g. Emilio Abi Aad's thesis in progress, Jaber et al, 2020).

Stakes for the doctoral student - Collaborations and conditions of realization

In addition to scientific publications, the student will be able to promote his experimental work in geomechanics, as well as his work in numerical modelling to many scientific and technical actors (CNRS, national and international universities). This thesis will also allow the student to use drilling data from IODP expeditions and to interact with the international community of ocean drilling, subduction zones, and seismology.The thesis student will be located at the GeoRessources laboratory in Nancy. He/she will benefit from the experience of his/her thesis supervisors in numerical mechanical modeling (e.g. Conin et al, 2012 ; Jaber et al, 2020 ; DeSantis et al, 2019 , DeSantis, 2020), in energy calculations (Hauquin et al, 2018), as well as in experimental work on fault shear (e. g. Jaber et al. 2020, Jaber et al. 2021), and on field data (M. Conin, and was part of the IODP campaigns conducted in Nankai and Tohoku). Moreover, the GeoRessources laboratory has a strong expertise in rock mechanics, recognized nationally and internationally, and has a long-standing interest in faulting.

He/she will also benefit from collaborations with P. Souloumiac (Univ. Cergy) who works on energy balances in accretion prisms from sandbox models, and N. Cubas (IsteP) who is working on the link between the morphology of prisms and the mechanical coupling of the subduction interface. He/she will have to discuss regularly with the national and international community working on these subjects, and will have to present his/her work in international conferences. A follow-up committee of the student will meet once a year to follow the progress of the thesis.

Application

Candidates should send an application form at Marianne Conin (marianne.conin@univ-lorraine.fr), and Yann Gunzburger (yann.gunzburger@univ-lorraine.fr) which includes :

1. A resume
2. A motivation letter
3. If possible 2 recommandation letters.

Deadline for application is the 2nd of November 2021.

Selected candidates will be interviewed in early November.