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TITRE du SUJET :

A physical modeling approach to understanding the source and dynamics of tectonic tremor, using insight from a variety of geological systems

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Research background and motivations

Earthquakes and eruptions are preceded and succeeded by long periods of energy loading, most appropriately observed with geodetic means, owing to their rate and scale of evolution. Within those latter phases of apparent inactivity, and in the direct run up and aftermath of catastrophic events, slow, transient energy release (STER) processes are active — slow-slip events, magma migration or degassing. It has been relatively recently noticed that STER processes are closely associated with tremor, a long, emergent, pulsating seismic signal, with a characteristic low-frequency content. Therefore, even in the absence of significant geodetic activity, tremors can still be used to assess a diagnosis of the system.

Within the tremor, bursts of low-frequency seismic energy are observed, emitted from point sources with clear S-waves arrivals. These are called low-frequency earthquakes (LFEs), or long-period earthquakes in volcanic contexts (LP earthquakes). These elementary low-frequency sources (ELFS) seem to be the elementary components of tremor. As such, they could offer glimpses of the STER process generating tremor at the most elementary scale (see illustration).

The strong, active implication of fluids seems to be a key in understanding tremor at its smallest scale. In a certain way, the link between the ELFS and the tremor scale is the way sources interact with each other, creating recurrence and migration patterns. The strongest interaction between ELFS happens in periods and regions where slow-slip is active. However, elastic stress propagation would create exteremely rapid interactions, whereas the migration velocities of LFEs during slow-slip are slower. Therefore, pore pressure transients seem to be the best candidates to explain such migration and recurrence patterns, acting as slow vector of stress, channeled through the fluid present in the fault zone.

The complex role of fluids in STER processes in faults — channeling stress, enabling rupture and even acting as a possible seismogenic source — motivates a cross-system approach. The physics of STER and the observations of tremor in volcanic systems and glaciers might give essential insight to understand the generation of tremor on faults.

This PhD project aims at using pore pressure propagation, fluid migration and fluid based seismogenic mechanisms to think of tremor and the STER processes underlying it at different scales within a new theoretical framework, enriching our current approach of the phenomenon.

We can list a few scientific questions that constitute the core of the project motivation:

• What are the seismogenic processes of elementary low-frequency sources and how do they relate to STER processes? How can they be modeled in accordance to observations and described processes the system in question?

• Bearing in mind the similarity of low-frequency seismic observations across different geological systems, to what extent can physical insight on the seismogenic process be drawn from different geological environments (eg: tectonic/volcanic/glaciers)?

• What are the processes controlling the complex interaction patterns of elementary sources? Can they be linked to source processes and thus allow to describe STER processes at different temporal and spatial scales? Can a statistical description of the recurrence and interaction of seismicity provide understanding of the state of the system?

• How can these models be integrated into a comprehensive framework of detection and characterisation of tremor, and provide diagnostic and/or prognostic information on a geological system?

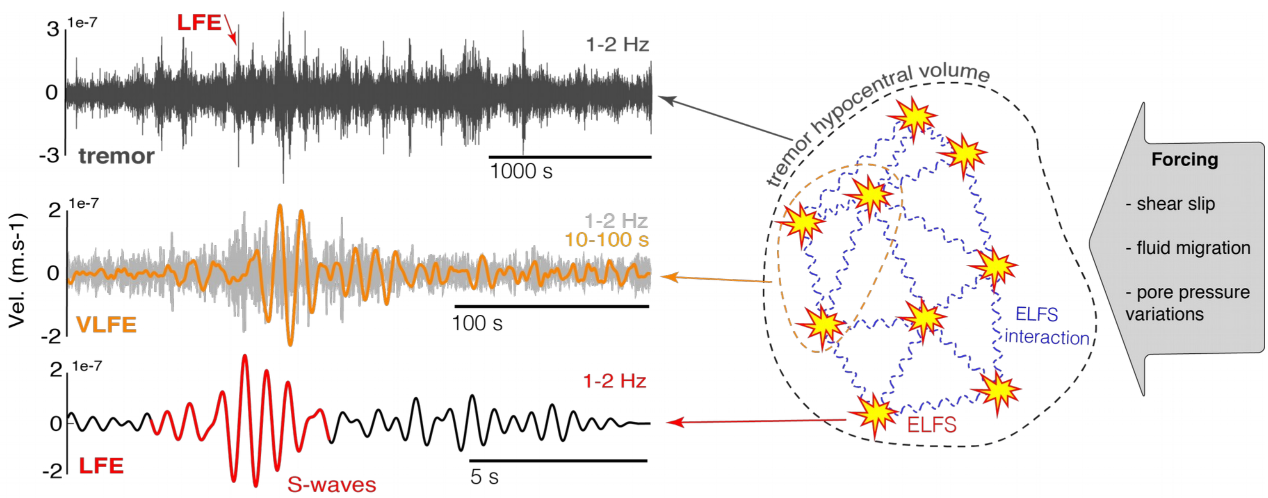

Illustration 1: Elementary low-frequency sources interaction - generation of tremor, VLFE, LFE

Methodology

We will try to provide answers to the previous research questions using simple physical models to explain different aspects of seismicity migration and recurrence patterns, visible in large catalogues of LFEs, mostly available online.

A few studies have developed models of pore-pressure propagation to explain tremor migration patterns and the large-scale interactions of slow-slip and fluid in fault zones [Cruz-Atienza et al., 2018]. On a smaller scale, we started developing model for short-scale interaction between ELFS. They are based on pore pressure diffusion in a permeable fault zone and aim at explaining the cascading activation of sources that form clusters of LFEs. The preliminary model represents ELFS as permeability valves barring the updip fluid flow and allowing for pore pressure build up and episodic release. Analysing how the distribution of ELFS and forcing conditions affect the statistics of source activation could explain aspects of patterns of recurrence and migration of tremor on the smallest scales. To achieve this, we will use statistical analysis tools and aim at developing a statistical model of source activation in presence of interactions. The obtained patterns of activation of ELFS, combined with basic LFE waveform modeling, would allow us to produce synthetic tremor signal, and perhaps exlpore the conditions of interaction, forcing and ELFS distribution to generate VLFEs.

Throughout the development of these models, we will test not only their ability to reproduce observed seismicity, but also the consequences of geological conditions represented by the control variables in our models : the fluid source, the preexisting stress field, the effect of slip on the fault. These conditions are a fundamental part of the picture if we are to investigate the reasons some regions are sources of tremor, while some other are not.

Tentative time schedule

Year 1 – Developing the ELFS interaction model, based on models of pore pressure propagation. Statistical analysis of modeled and observed seismicity patterns.

Year 2 – Developing models of LFE, VLFE and tremor seismogenic source physics, based on the interaction patterns emerging from fault-valve models and comparison to volcanic and glacial tremor sources.

Year 3 – Integration of work on sources and interactions into a common framework, plans to develop diagnostic and prognostic models.