Rumbling Tectonic Plates – Probing Fault Stresses with Non-volcanic Tremor

Supervisors: Dr. Ben Edwards, Dr. Pablo Gonzalez, Prof. D. Faulkner
External supervisors and institution: Prof. Stefan Wiemer
Primary Contact Name and Email: Dr. Ben Edwards (ben.edwards@liverpool.ac.uk)

Is this a CASE studentship? YES
If so, please state intended CASE partner:
Swiss Seismological Service

Introduction

Understanding stress accumulation and release along active fault zones is a fundamental challenge in seismological research. Only with a complete understanding of the mechanisms of plate motion will we have the possibility to reliably estimate seismic hazard at plate boundaries. Current understanding of plate tectonics assumes that accumulated strain energy along plate boundaries is released either through continuous dislocation creep or, in locked parts of seismogenic faults, through infrequent large (**M** > 8) earthquakes. However, it is becoming increasingly evident that there exist further intermediate, and detectable, mechanisms that can accommodate a significant proportion of plate movement.

Over the last decades, increasingly sensitive seismic networks have enabled the discovery of additional slip phenomena, such as slow slip events, low and very low frequency earthquakes and non-volcanic tremor (NVT) (Shelly *et al.*, 2006, Rogers and Dragert, 2003). Much about these signals remains to be investigated, including their overall role in stress release and resulting effect on seismic hazard.

Non-volcanic tremors (NVTs) are observed in transition zones between freely slipping and locked sections of faults and normally occur below the seismogenic zone. Activity is characterized by low amplitude seismic signals lasting a few minutes to several days with frequency content usually concentrated between 1 and 15Hz. They have been documented at several tectonic plate boundaries around the world, both in subduction zones and near transform faults, extending below the seismogenic zone (Obara, 2002, Nadeau and Dolenc, 2005). These

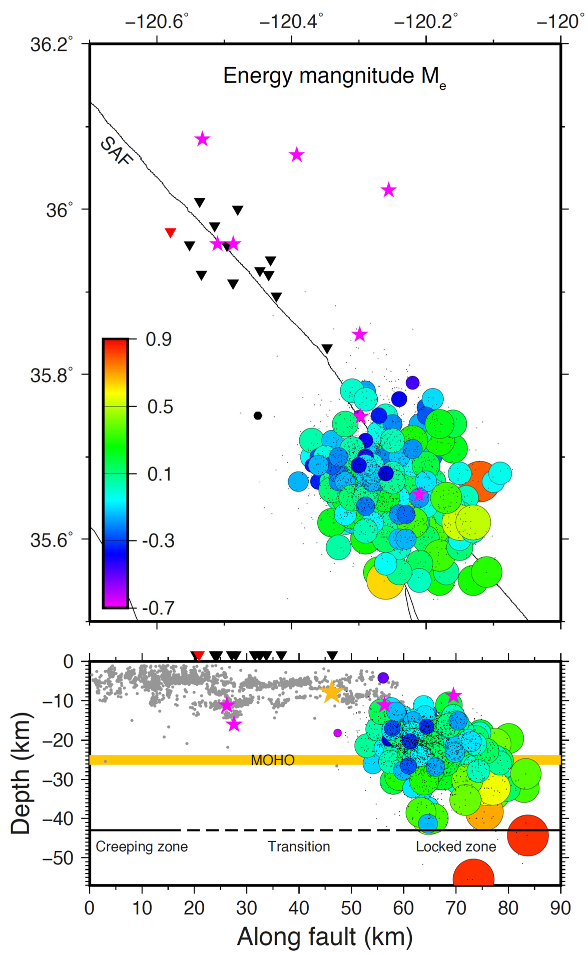

Figure 1**:** distribution of NVT at the San Andreas Fault. Circle sizes and colours scale with M_e (where available, otherwise location indicated by grey dot). Grey circles (cross section) and pink stars represent locations of selected earthquakes. Seismic stations of the High Resolution Seismic Network are shown by inverted triangles.

events offer the possibility to detect plate motion, and therefore infer stress and strain, at depth.

Recent work has attempted to characterize and quantify NVTs in terms of magnitude of moment and energy release (Staudenmaier *et al.*, 2016) in addition to their frequency of occurrence (Staudenmaier *et al.*, 2017). These studies showed that a significant proportion of slip (up to 100 %) is accommodated through processes generating NVTs. Understanding the accommodation of plate movement clearly has strong implications on seismic hazard: being able to map regions of stress accumulation will allow us to more reliably forecast devastating earthquakes.

Project Summary

This project will further our understanding of plate motion through the detection, characterization and modelling of non-volcanic tremor (NVT) signals at plate boundaries such as those in California, Oregon, and Japan. You will use advanced seismological techniques for large data collection, processing and analysis:

- NVT catalogues will be refined by applying the method of Staudenmaier *et al.* (2016) to existing NVT detections. Catalogue completeness will then be assessed using continuous seismic recordings.
- Seismic moment and energy release will be measured and mapped using spectral analysis techniques: spectral fitting and empirical Green's functions. Comparisons with earthquake records will be made to understand similarities and differences of propagation – for example by measuring attenuation.
- Static and dynamic characteristics of NVTs in different setting will be investigated – for instance is there a change in the spectral characteristics (both overall and time-variant) at the different margins, or locations within each.
- Modelling approaches will be used to understand the mechanisms required to generate NVT signals: this will include interpreting laboratory measurements, and generating computer models of plate motion.
- Measurements of surface creep (GPS measurements) will be used to link surface motion to the slip at depth allowing us to understand the potential stress build-up in the upper crust.

The overall aims of the project will be to produce numerical models that are supported by rock mechanics laboratory experiments and to provide a conceptual model for how this can inform us of seismic hazard both in terms of the state of stress and any time-variant evolution. The candidate will gain a unique training in the use of large seismological datasets, programming, and have the opportunity to perform field and laboratory experiments. Students with a strong background in geophysics, geology, maths, physics, or engineering are encouraged to apply.

References

Nadeau, R. M. and D. Dolenc (2005). Nonvolcanic tremors deep beneath the san andreas fault, *Science* **307** (5708), 389-389**.**

Obara, K., 2002. Nonvolcanic deep tremor associated with subduction in southwest Japan. Science, **296** (5573), pp.1679-1681.

Rogers, G. and H. Dragert (2003). Episodic tremor and slip on the cascadia subduction zone: The chatter of silent slip, *Science* **300**, 1942-1943.

Shelly, D. R., G. C. Beroza, S. Ide and S. Nakamula (2006). Low-frequency earthquakes in shikoku, japan, and their relationship to episodic tremor and slip, *Nature* **442**, 188-191.

Staudenmaier, N., B. Edwards, T. Tormann, J. D. Zechar and S. Wiemer (2016). Spatial distribution and energy release of nonvolcanic tremor at parkfield, california, *Journal of Geophysical Research: Solid Earth* **121**, 8833-8854.

Staudenmaier, N., T. Tormann, B. Edwards and S. Wiemer (in press). Moving tectonic plates through non-volcanic tremors and nano-earthquakes, *Nat Commun.*