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Investigation of Earthquake Nucleation and Precursors, from Laboratory and Satellite Observations (Ref IAP-17-147)

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In partnership with School of Engineering, Newcastle University

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Key Words	Geohazards; Earthquake mechanics; InSAR;

Overview

Until very recently the occurrence of aseismic slip as a precursor to major earthquakes was almost completely unknown. But large, aseismic slip episodes lasting several weeks or more have been identified immediately preceding the Mw 9, 2011 Tohoku and Mw 8.1, 2014 Iquique earthquakes (Fig. 1), and aseismic slip has also been observed as part of the nucleation process of laboratory-simulated earthquakes. The temporal and spatial scale of this nucleation process varies in the laboratory, and extrapolation of these results using numerical models up to the scale of natural earthquakes suggests the process follows a common, self-similar pattern. In addition, more pervasive aseismic slip preceding earthquakes is suggested by small-magnitude seismic activity before tens of large magnitude intra-plate events. Investigation of precursory slip and the nucleation process is fundamental to improving our understanding of earthquake mechanics, and in addition could lead to major improvements in earthquake early-warning, where rapid alerts are delivered to at-risk populations as soon as the start of an earthquake is detected.

However, neither the conditions required for generating pre-seismic slip nor the commonality of these events in nature are known. The conditions which determine the size and duration of pre-slip have never been systematically explored, and experimental results have mostly been obtained using synthetic materials rather than fault rocks. And whilst most shallow, large earthquakes are routinely analysed with geodetic data, observations of precursory deformation are extremely rare: a systematic search from these data has not been attempted. This project aims to address these gaps in our understanding by using both laboratory experiments and satellite-based remote-sensing techniques to investigate earthquake nucleation at vastly different, but complementary spatial and temporal scales.

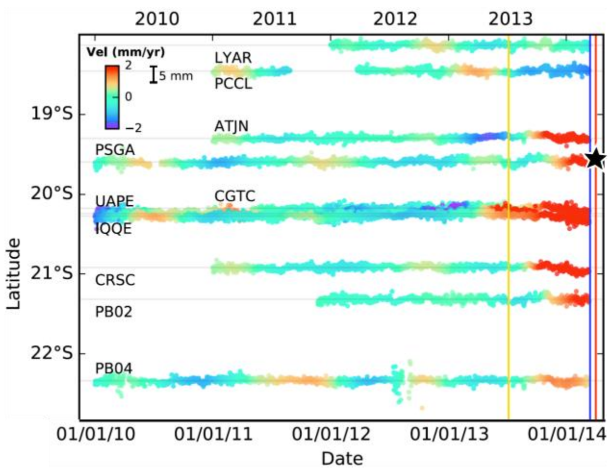

Figure 1: Preseismic ground deformation obtained in the years preceding the Mw 8.1 megathrust earthquake of April 1, 2014 (Iquique, North Chile). Colours indicate the trench-perpendicular, GPS-measured velocity at each coastal station, with a clear acceleration (red) at 7 stations. Adapted from Socquet et al. (2017).

This work will have several aims, all addressing the important question of what factors control the size and duration of the nucleation phase:

- Systematically analyse satellite radar data following major earthquakes worldwide in order to place constraints on the size and duration of any precursory slip before natural earthquakes.
- Test how fault structural properties such as roughness, thickness of gouge, segmentation, fault topography and inhomogeneity control nucleation size in the laboratory.
- Investigate how nucleation size, amplitude and duration of pre-slip, as well as the magnitude of the subsequent earthquake, are correlated in both lab-

generated and natural earthquakes.

Methodology

For all Mw > 6 earthquakes since 2014, interferometric SAR (InSAR) will be used to analyse deformation signals over the epicentral region in the 6 to 12 months preceding the event. Data processing will largely take place at the COMET (Centre for the Observation and Modelling of Earthquakes, Volcanoes and Tectonics) automated InSAR processing facility hosted at Harwell. Atmospheric correction techniques will be used to mitigate the influence of atmospheric noise on our data and kinematic inversion will be used to separate coseismic from preseismic slip (e.g. Floyd et al., 2016). We will analyse each pre-slip period individually, as well as stacking fault pre-slip for multiple events to increase the signal-to-noise ratio.

Laboratory experiments allow simulation of faults under loading conditions representative of the upper crust. Rupture growth will be tracked by instrumenting rock samples with an array of sensors (strain gauges and piezo-electric transducers), and recorded on a 24 channel system. In addition, tests on transparent synthetic samples (Figure 2) will be performed using high-speed photographic equipment. The acoustic/strain data from the simulated faults will allow us to:

(1) measure of the precursory strain and emissions in the hours preceding rupture;
(2) explore the parameters which control nucleation size and duration (fault composition and structure, loading rate, friction);
(3) define the scaling relations that apply within the range of magnitudes obtained in the lab, and their extrapolation such scaling to real Earth using numerical models.
(4) test the hypothesis that faults with less mature and less homogeneous structure tend to produce more instability and smaller nucleation lengths.

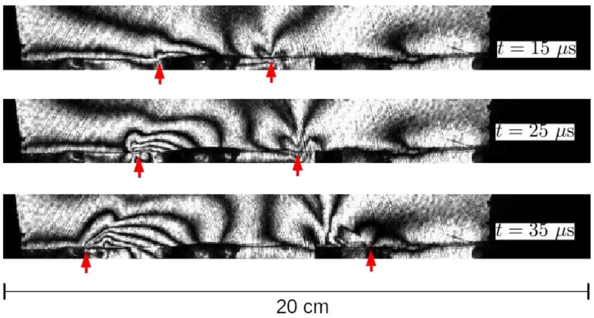

Figure 2: Laboratory experimental fault with a rupture nucleating (15 µs), accelerating (25 µs) and propagating dynamically (35 µs). The edges of rupture are indicated by the red arrows in the three successive snapshots. Interferometric fringes show the stress concentration.

Timeline

Year 1: Training in space geodesy techniques, in particular the handling of satellite radar data. In parallel, training will be provided on setting up laboratory experiments of synthetic earthquakes. Initial processing and analysis of radar data for selected earthquakes.
Year 2: Continuation of laboratory experiments, radar data processing and analysis. Detailed analysis of one precursory event. The work from Years 1 and 2 should lead to at least one publication in an international journal.
Year 3: Analysis of completed InSAR-derived catalogue of deformation events. Comparison of remote sensing and laboratory results. This work should lead to an additional publication.
Year 4 (6 months): Combining the published outputs and associated material into a PhD thesis.

Training & Skills

The student will receive training in space geodesy techniques, in particular the handling of satellite radar data, in modelling co- and preseismic deformation, and in setting up and running laboratory simulations of earthquakes and pre-seismic slip. Training in a wide range of essential skills (e.g. presentation skills, paper/thesis writing, and enterprise skills) important both for life as a PhD student and afterwards is provided by the Department of Earth Sciences at Durham University, and the student will also benefit from cross-disciplinary training provided as part of IAPETUS.
The student will become a member of COMET benefitting from the shared expertise of Geosciences staff in several universities, and attending regular meetings where the research of these various groups is discussed.
The student will have opportunities to work with other partners in the UK and internationally and they are encouraged to travel to national and international scientific meetings to present results. We aim to see all students publish at least two papers in leading scientific journals during their PhD. Upon completion, the student will be well equipped for a career in academia or in a range of industries.

References & Further Reading

Floyd, M.A., **Walters, R.J.**, Elliott, J.R., Funning, G.J., et al., 2016. Spatial variations in fault friction related to lithology from rupture and afterslip of the 2014 South Napa, California, earthquake. Geophysical Research Letters, 43(13), pp.6808-6816.
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megathrust. Geophysical Research Letters, 44(9), pp.4046-4053.

Further Information

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