Role of slow slip in the earthquake cycle: from laboratory scale to satellite observations (Ref IAP2-18-185)

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Overview
Over the last decade, large, slow slip episodes (SSEs) lasting several weeks or months have been identified on major earthquake faults. As data resolution increases, the abundance of SSEs indicates that they are not mere side-effects, but a key component in the dynamics of the seismic cycle. Space geodetic data show that some SSEs immediately precede earthquakes (Mw 9, 2011 Tohoku; Mw 8.1, 2014 Iquique earthquakes, Fig. 1); more pervasive aseismic slip is suggested by small-magnitude seismic activity before tens of large magnitude intra-plate events. Aseismic slip is also observed as part of the nucleation process of laboratory-simulated earthquakes. This calls for a deeper understanding of (1) the role of SSEs in fault slip at all scales, and in particular (2) the interaction between SSEs and earthquake ruptures. SSE processes are fundamental to our understanding of earthquake mechanics, and could lead to major improvements in earthquake risk evaluation and mitigation (e.g. global hazard assessment, early warning techniques).

However, neither the conditions required for generating pre-earthquake SSEs 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.

This work will have several aims, all addressing the important question of what is the relation between SSEs and earthquake rupture. The candidate shall:
- Systematically analyse satellite radar data in the months preceding major earthquakes worldwide in order to place constraints on the size and duration of any SSE 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 near/on-shore 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. Atmospheric correction techniques will be used to mitigate the influence of atmospheric noise on our data and time-series inversion methods will be used to separate coseismic from preseismic slip (e.g. Floyd et al., 2016, Gualandi et al. 2017). 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 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/analysis. Detailed analysis of one precursory event. The work from Years 1 & 2 should lead to at least one publication.

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.

Final 6 months: Focus on combining the published outputs and associated material into a PhD thesis.

Training & Skills

The student will receive training in processing, analysing and modelling satellite radar data, 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) 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 the UK’s Centre for the Observation and Modelling of Earthquakes, Volcanoes and Tectonics (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. We aim to see all students publish at least two papers in leading scientific journals during their PhD and present results at national and international scientific meetings. 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., et al., 2016. Spatial variations in fault friction related to lithology from rupture and afterslip of the 2014 South Napa, California, earthquake. GRL, 43(13)


Further Information

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