Project Title:
Seismicity and Structure of Subducting Slabs

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Summary

This project aims to understand the distribution of seismicity associated with internal deformation in shallow subducting slabs. Subduction zones are well known to host the largest and most damaging earthquakes, but also a wide variety of smaller events. The distribution and style of this seismicity is essential for our understanding of the seismic hazard posed by subduction zones, and also provides critical information on the dynamics of the subduction process.

Subduction zones host the majority of the Earth's seismic moment release. Whilst much of this is the result of motion between plates along the plate interface, significant seismicity also occurs within subducting plates, as they deform internally. Although they rarely reach the size or frequency of earthquakes associated with the subduction megathrust, these earthquakes, often located deep beneath cities landwards of major subduction zones, have the potential to be devastating, as seen in the magnitude 7.9 1970 Ancash (Peru – the deadliest earthquake in South American history), the 2001 magnitude 7.7 El Salvador earthquake, and, more recently, the magnitude 7.1 2017 Puebla/Mexico City earthquake (e.g., *Melgar et al., 2018*). In many cases, the occurrence of such earthquakes remains a surprise, with the capacity of the downgoing plate to host such large-magnitude earthquakes uncertain in many regions.

These earthquakes arise from the combination of the stresses derived from large-scale plate-driving forces, localised stresses arising from changes in slab geometry (e.g., changes in slab dip, slab tears, etc – see Figure 1), and rheological factors relating to the structure and evolution of the subducting plate as it descends into the Earth's interior (*Hacker et al., 2003; Abers et al., 2013*). Critical to understanding the distribution of such earthquakes is our ability to accurately map out their location within the plate, in particular with respect to each other, and to the surface of the subducting plate (e.g., *Abers et al., 2013*). This project will initially focus on improving earthquake catalogues for a number of regional case studies (starting with Central and South America), accurately mapping out the seismogenic structure of the subducting oceanic plate, the location and mode of failure of active faults within the plate, and how the distribution of stress and strain vary within the plate. This will principally be done through the detailed analysis and modelling of global seismic data, incorporating locally-acquired data where available and useful. Many of the techniques required have been previously developed, but the student will tailor existing approaches to the requirements of the study and datasets available, and will be involved in the development of new approaches to the assessment of the seismic data as required.

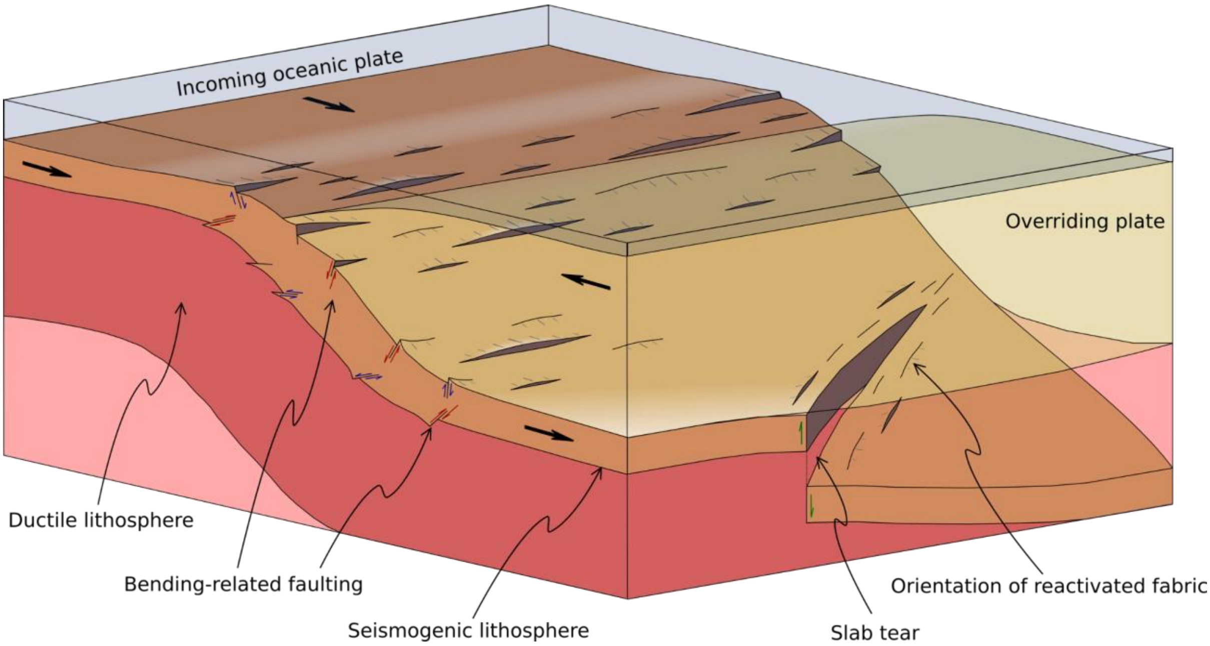

Figure 1: Schematic diagram illustrating intraslab faulting and seismicity.

The project will also aim to answer the question of how these earthquakes relate to the geodynamic setting of the slab, and its structure and rheological evolution, through the combination of seismological observations and geodynamic modelling (*Hacker et al., 2003*). Improved controls on the location of slab seismicity will allow us to develop our understanding of how these earthquakes relate to the thermal structure of the slab as it starts to heat up, and the mineralogical phase transitions that the slab undergoes during subduction, and the role that these processes may play in localising or triggering seismicity.

A final aim will be to understand the relationship between the largest earthquakes occurring in such settings (M7-8), and the background seismicity in their vicinity. In particular, addressing the issue of how these earthquakes activate such large sections of the seismogenic slab, and whether their spatial occurrence can be predicted, and incorporated into seismic hazard models. Understanding the rupture extent of these earthquakes in comparison to the seismogenic structure of the slab, will allow us to address the question of what these earthquakes can tell us about both the geodynamics of the slab (Do such earthquake rupture the full extent of the seismogenic slab? Do they rupture through both double seismic zones?), and may also throw light on their causative mechanism, through comparison to smaller seismicity (e.g., *Craig et al., 2014*). This aspect of the project may involve more complex seismological modelling of these earthquakes, and consideration of their aftershock sequences.

Whilst the initial work will focus on Central and South America (examples from Northern Chile shown in Figure 2), the expansion to incorporate other tectonic regions, particularly in the event of important new data (either due to increased instrument coverage, or to the occurrence of particular earthquakes), is a further avenue for developing the project in later years.

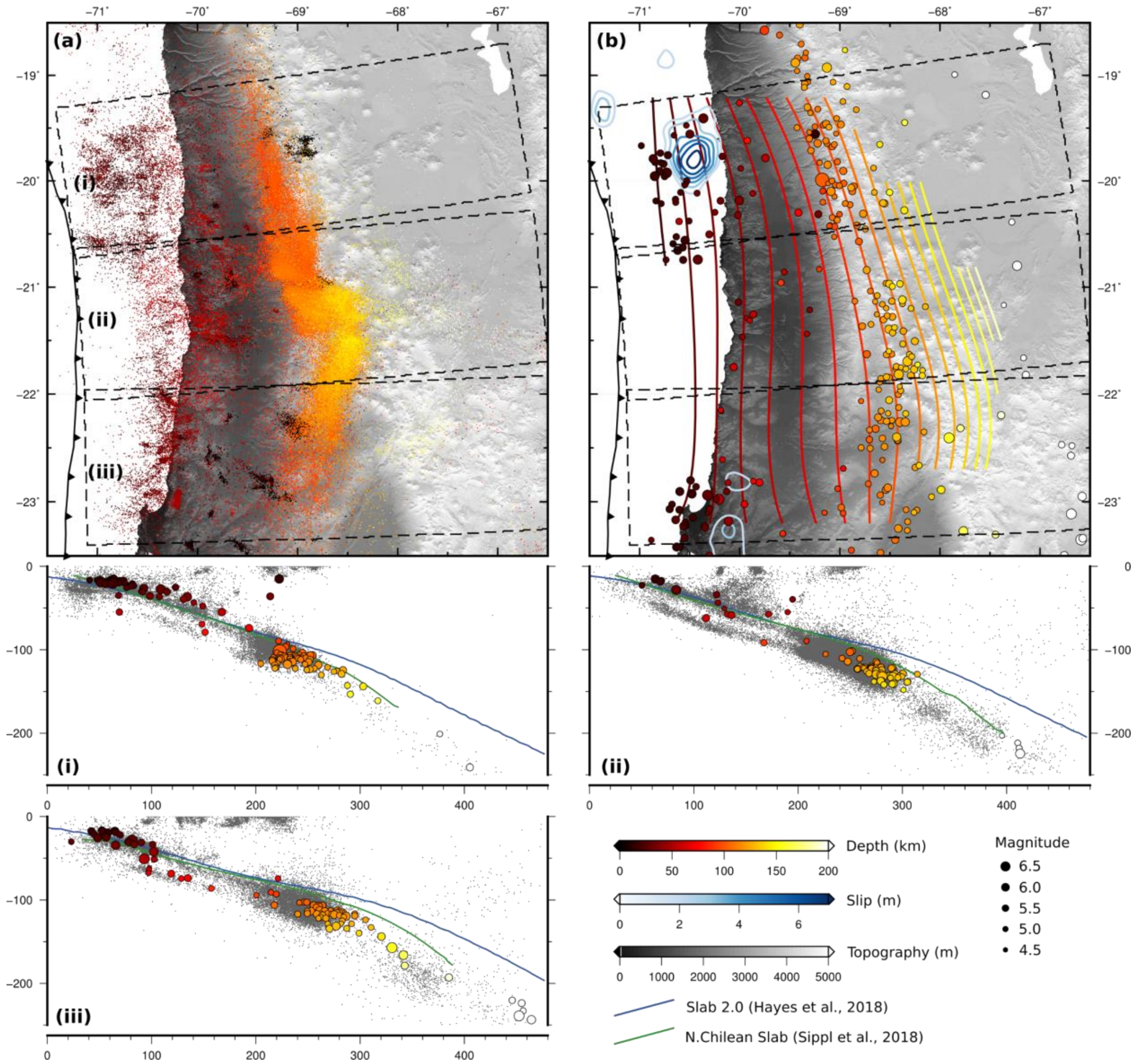

Figure 2: Intraslab seismicity in the North Chilean Subduction Zone. (a) Microseismicity shown is from the catalogue of Sippl et al., (2018), coloured by depth. Dashed outlines indicate the extents of the cross-sections shown in (i) -- (iii). (b) Earthquakes with teleseismically-determined depths from this study. Slip contours (blue) show the rupture extents of the 1995, 2007, and both 2014 (all M>7.5) earthquakes. Contours shaded by depth are the slab-surface. (i) -- (iii) Cross sections show seismicity reprojected for each profile as shown in (a). Grey dots are microseismicity from Sippl et al., (2018). Coloured points are earthquakes from this study. Lines show the mean depth to the slab top for each distance for Slab 2.0 (Hayes et al., 2018) and from Sippl et al., (2018). Figure from Craig (in prep).

References:

- Hacker et al., (2003). Subduction factory 2. Are intermediate-depth earthquakes in subducting slabs linked to metamorphic dehydration reactions? *Journal of Geophysical Research*, 108:2030. doi:10.1029/2001JB001129.

- Abers et al., (2013). Thermal-petrological controls on the location of earthquakes within subducting plates. *Earth and Planetary Science Letters*, 369-370:178-187. doi:10.1016/j.epsl.2013.03.022.
- Craig et al., (2014). A reassessment of outer-rise seismicity and its implications for the mechanics of oceanic lithosphere. *Geophysical Journal International*, 197:63-89. doi:10.1093/gji/ggu013.
- Melgar et al., (2018). Bend faulting at the edge of a flat slab: the 2017 Mw 7.1 Puebla-Morelos, Mexico Earthquake. Geophysical Research Letters, 45:2633-2641. doi:10.1002/2017GL076895.
- Sippl et al., (2018). Seismicity structure of the northern Chile forearc from >100,000 double-difference relocated hypocenters. *Journal of Geophysical Research*, 123:4063–4087. doi: 10.1002/2017JB015384.

Objectives:

In the initial case, you will work to accurately map out the occurrence and style of seismicity in the shallow subducting plates beneath Central and South America to understand the relationship between event locations, seismogenic zones and the dynamics of the slab. Depending on your interests, this will be followed by in-depth investigation of the controls on the occurrence of large-magnitude earthquakes within the subducting plate, understanding and mitigating the seismic hazard posed by intraslab seismicity, how the seismogenic structure of the plate responds to the evolving structure and rheology of the plate, and how intraslab seismicity can be used to probe the structure or composition of the subducting slab.

Applicant Background:

This project would suit candidates with a background in quantitative geology, geophysics, or physics with an interest in solid-Earth processes. Prior skills in observational seismology or numerical geodynamic modelling are desirable, but not required.

Training:

The student will work under the supervision of Dr. Tim Craig and Dr. Sebastian Rost, within the Institute for Geophysics and Tectonics. The student will receive training in observational earthquake seismology and numerical geodynamic modelling, with a focus on earthquake location and kinematics. They will also receive additional training through the Doctoral Training program hosted by the Faculty of Environment and the University of Leeds and the Doctoral Training Partnership. Within Leeds, they will have the opportunity to interact with internationally-excellent research groups in Tectonics and in Deep Earth Dynamics, hosted within the Institute for Geophysics and Tectonics. The School also hosts numerous staff from the NERC-funded Centre for the Observation and Modelling of Earthquakes and Tectonics (www.comet.nerc.ac.uk), with whom the student will be able to interact.