

Validating Earthquake Hazard Models for Critical Engineered Structures Using Geologic Data and Cosmogenic Isotopes

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Background: Earthquakes can be profoundly destructive to societal infrastructure, human life, and the environment; recent examples include the 2011 Christchurch and Tohoku earthquakes. Probabilistic Seismic Hazard Analysis (PSHA) is the regulatory required approach to assessing the earthquake hazard and risk in the engineering of sensitive structures, e.g., nuclear facilities, dams, bridges, and hospitals. The goal of PSHA is to assess the rate (or probability) of exceeding an amount of shaking at a site, which requires an understanding of the earthquake source and seismic wave attenuation relations. Empirical data is critical to accurate PSHA, and the length of the earthquake cycle precludes the use of historical observations to assess longer-term patterns of seismicity; **geologic data is the only tool available to test PSHA models over timescales 1 ky - 1 My**. Cosmogenic isotopes (Granger et al., 2013) provide a unique and powerful tool for the assessment of earthquake hazards. This project will apply cosmogenic isotopes to the assessment of earthquake hazards around the world (e.g. California, New Zealand, Iceland, Portugal), including earthquake dating of fragile geologic features (Balco et al., 2011), fault slip rates (Rood et al., 2011), and unconventional paleoseismology.



Methods: The primary goal of this PhD project is to combine geologic and geomorphic data with cosmogenic isotope exposure ages to reconstruct or place limits on the magnitude of past earthquake ruptures and ground motions, quantify deformation rates across active structures (faults and folds), and date ancient earthquake events. An important aspect will be

to precisely date important Quaternary landforms and strain markers, which have poor age constraints and provide important constraints on earthquake hazards. The PhD student will:

- 1) Create detailed digital geologic and geomorphic maps (using lidar data and ArcGIS), including mapping of deformed strata and deposits along major structures (e.g. offset alluvial fans and uplifted marine terraces);
- 2) Determine the ages of strata and deposits exposed along faults utilizing cosmogenic isotope exposure ages and isochron burial dating methods;
- 3) Combine geochronology results and structural analysis to precisely quantify the timing and rate of deformation on the faults and folds;
- 4) Use cosmogenic isotope analyses with numerical forward models (using MATLAB and photogrammetry software) to date fragile geologic feature (e.g. precariously balanced rocks) and constrain the upper limit of ground motion (shaking) using finite element modelling, which will be synthesized to test seismic hazard models;
- 5) Further develop novel cosmogenic isotopes exposure dating methods to resolve timing, frequency, slip per event, and rupture length of ground rupturing earthquakes, and assess regional spatial patterns of strain release (e.g. by dating bedrock fault scarps and rock falls).

Outcomes: This project will produce new ages for key geomorphic features, and use them to test earthquake hazard models and calculate deformation rates. Developing such datasets will directly contribute to and reduce uncertainties in earthquake hazards assessments for regions around the world where significant human population and critical infrastructure (e.g. hydroelectric dams in California, USA) exists. Results will be published in high-profile journals and the PhD student will have the opportunity to present major findings in at least one international conference.

Training: The ideal candidate will be interested in engineering geology, field geology, geomorphology, isotope geochemistry, numerical modeling, and hazard analysis. This project will provide development of skills and experience across the geosciences, including tectonic geomorphology, structural geology, geophysics, geo- and radiochemistry, nuclear physics, and geohazard assessment and mitigation. Skills will be developed in field data collection, chemistry and accelerator mass spectrometry laboratory procedures, and numerical modelling methods. Importantly, integrating data and observations at the intersections of these disciplines will be a unique quality of this project. **A passion for science that matters to society is critical.** This is a multidisciplinary project, with significant training in field, laboratory, and analytical methods. Fieldwork (including mapping and sample collection) will be conducted in field areas around the world; the candidate should be prepared to camp for significant periods of time and must be able to drive a vehicle. Laboratory work will involve mineral separation and chemistry preparation of cosmogenic isotope samples in Imperial's CosmIC labs; the candidate should thus be meticulous and attentive to detail. Analytical work will involve travel to Australia or the San Francisco Bay Area (USA) for Accelerator Mass Spectrometry (AMS) measurements, and/or Los Angeles area (USA) for noble gas mass spectrometry analyses at Caltech. The student will collaborate with international project partners in academia, government, and industry, and establish skills and networking connections important for further career opportunities in these scientific realms.

References:

- Balco, G., Rovey, C.W., 2008, An isochron method for cosmogenic-nuclide dating of buried soils and sediments, *American Journal of Science*, 308, 1083.
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- Granger, D.E., Lifton, N.A., Willenbring, J.K., 2013, A cosmic trip: 25 years of cosmogenic nuclides in geology, *Geological Society of America Bulletin*, 125, 9-10, 1379-1402.
- Rood, D.H., Burbank, D.W., Finkel, R.C., 2011, Spatiotemporal patterns of fault slip rates across the central Sierra Nevada Frontal Fault Zone, *Earth and Planetary Science Letters*, 301, 457-468.