SCEC ANNUAL REPORT
for 2009

Age of Precarious Landforms Near Major Plate Boundary Faults in New Zealand: Cross Validation of Western United States Studies

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Introduction

The fundamental objective of our 2009 SCEC-funded work has been to undertake initial groundwork to constrain the upper-bounds of near-field earthquake motions from great plate boundary Alpine Fault earthquakes. There is a paucity of instrumental strong motion data close to major earthquakes, and the relatively few well-instrumented events dominate the worldwide strong motion datasets (e.g. Chi Chi Taiwan). There are currently no strong motion records for near-field Alpine Fault earthquake motions, and our application of standard methods of probabilistic seismic hazard assessment (PSHA) predict increasingly stronger motions as a function of return period close to the fault (peak ground accelerations or PGAs of c. 0.9g, 1.4g and 1.6g at the 475 year, 2500 year and 5000 year return periods, respectively). There is currently no procedure for verifying whether these hazard estimates are realistic for the Alpine Fault, a mature plate boundary fault with nearly 500km of accumulated offset.

Our approach to constraining the upper-bounds of Alpine Fault motions is to use natural bedrock landform features as low resolution seismoscopes that have "recorded" past Alpine Fault events. Specifically, we seek to quantify the age and fragility of the landforms in order to say "ground motions beyond level X could not have happened at this site for Y years or the features would have been destroyed". The fundamental methodology of using fragile landforms in this manner was originally developed in the USA by Brune & Whitney (1992), and has been further developed (e.g. Whitney et al., 2008; Stirling et al. 2010) and also applied to New Zealand in EQC/SCEC co-funded work (e.g. Stirling & Anooshehpoor, 2006; Stirling et al. 2009). The co-funded studies of unstable precariously-balanced rocks (PBRs) at a near fault site in central Otago established the PBRs to be of Holocene age (i.e. considerably younger than PBRs in arid USA environments), too young to be useful for testing ground motions at active faults with recurrence intervals of greater than 10kyrs. Use of PBRs and fragile bedrock landforms will instead be useful near faults with short recurrence intervals (0.1-1kyr), as is certainly the case for the Alpine Fault.

Reconnaissance Visit to Field Area

The Hohonu Range is situated very close to the central section of the Alpine Fault (5 to 10km distance; Fig. 1) yet relatively fragile granitic outcrops and perched boulders are present on the summit ridges and cirque headwalls (Fig 2). Our 2009 SCEC funded work involved a reconnaissance fieldtrip to one of the summit ridges in February to observe these landforms, followed by presentation of our observations at the SCEC Annual Meeting, and development of a follow-up workplan. The landforms in Figure 2 show weathering features on the granite surfaces that appear old enough for the outcrops and boulders to have survived repeated nearby Alpine Fault earthquakes (3 to 5 near-field earthquakes in the last 1000 years; Langridge et al. 2009). Specifically, weathering pits were observed that would have taken millennia to form, and the largest lichens would have taken centuries to form. In short our observations are such that a more in-depth study of the age and constraints on Alpine Fault near-field motions is warranted.

Future Work

Future work (should additional funding be forthcoming) will comprise a study of the age of a representative selection of granitic landforms (specifically rock outcrops and perched boulders; Fig. 2), along with engineering geology and geotechnical stability assessments of the landforms to determine the ground motion levels that would likely lead to their failure. Logically, these are ground motion levels that have not been exceeded while the fragile landforms have been in their present fragile state. The age of the features, and by inference the number of great Alpine Fault earthquakes they have survived, will also be assessed. The approach will therefore provide constraints on near-Alpine Fault ground motions for time periods equivalent to the age of the landforms.

Our study will comprise site selection, description of relevant landform features, assessment of the strength of earthquake motions that would shake the landform features down, relative and absolute surface dating of the landform features, comparison of threshold ground motions to predicted Alpine Fault motions, and report preparation. The following describes the methodology in four phases:

(1) Geomorphological assessment using aerial photos to identify and select the most appropriate sites, utilising a systematic geomorphic-based classification scheme to rank the various landforms, taking into account the observations from the brief reconnaissance (Fig. 2). Remotely select six summit ridge sites where fragile granitic outcrops are present (cirque headwalls and ridge crests and tors; Fig. 2) and distributed more-or-less uniformly across the Hohonu Range at different distances from the Alpine fault. The spatial distribution of sites will range from about 5 to 10km distance from the Alpine Fault (Fig. 1). One site will be able to be described from the existing reconnaissance data and images (Fig. 2).

(2) Field-based description and sampling of relevant features for surface age dating: We will undertake a field based engineering geological assessment of each of the six sites, and make observations/take samples for surface age dating. The following techniques will be employed:

  (a) Engineering geological site assessment
    i. Field mapping of the site
    ii. Description of the rock masses for engineering purposes (QJEG, 1977)
    iii. Identification of likely failure modes (Hoek and Bray 1997)
    iv. Index testing to derive intact material strengths

   v. Identification and surveying of critical sections to facilitate the stability analyses

(b) Age dating

   i. Relative: Lichen development (e.g. Bull, 2003). Careful evaluation of methodology prior to use.
   ii. Relative: Surface weathering, i.e. weathering pit development and quartz/feldspar crystal emergence (e.g. Malcolm-Hall & Morton-Phillips, 2006)
   iii. Absolute: ^{14}C dating of organic material buried by nearby rockfalls and/or dendrochronology of trees growing on nearby rockfall surfaces. This will serve the purposes of calibrating (i) and (ii) as they also occur on boulder surfaces within the rockfalls. Access to the six sites will be by helicopter, and budgetary allowance will be made for 10 AMS ^{14}C dates that will be provided by the Rafter Radiocarbon Laboratory of GNS Science

(3) Geotechnical stability assessment of the fragile landforms using SLIDE, PHASE or UDEC software. The software used to assess the stability of each feature will depend upon the likely failure mode. The factor of safety at each feature (ratio of resisting to sliding forces) under static conditions will be assessed (will be greater than one for the landform features in the absence of earthquake shaking), coupled with a sensitivity analysis for changes in material parameters and discontinuity variability. Once the stability of each feature has been assessed the peak ground acceleration (PGA) required to reduce the slope factor of safety to about one (initiation of failure) will be determined. Given that the seismic hazard of the range is dominated by near-field Alpine Fault earthquakes (e.g. Stirling et al. 2002), the upper and lower-bound ground motions (PGA and possibly peak ground velocity, PGV) will then be compared to the predicted ground motions from both scenario Alpine Fault motions (median, 84^{th}, 95^{th} percentiles of PGA and PGV) and probabilistic ground motions equating to the number of Alpine Fault earthquakes the landforms have experienced. The latter will use findings from (2) above together with the number of Alpine Fault earthquakes over the time period the landforms have been present (Langridge et al. in review). Ground motion predictions for Alpine Fault earthquakes will be made by way of the New Zealand attenuation model (McVerry et al. 2006) and Next Generation Attenuation (NGA) models.

(4) Synthesis and report preparation: The final report will describe the study methodology and findings (age and upper-bound ground motions implied by fragile landforms), and will compare these ground motion constraints to the predicted scenario and probabilistic ground motions for near-field Alpine Fault earthquakes. This comparison will provide a valuable constraint on the near-field ground motions for great Alpine Fault earthquakes.

Conclusions

Our 2009 SCEC-funded work has involved: (1) a reconnaissance visit to an area where fragile granitic landforms are present close to the Alpine Fault, a major plate boundary fault in New Zealand; (2) presentation of the observations in a poster at the SCEC Annual meeting, and ; (3) development of a follow-up workplan. The reconnaissance study has identified features worthy of, and amenable to, age dating and stability analyses, which will then be used to place constraints on past near-field Alpine Fault motions. The follow-up workplan will be pursued if additional funding is forthcoming.

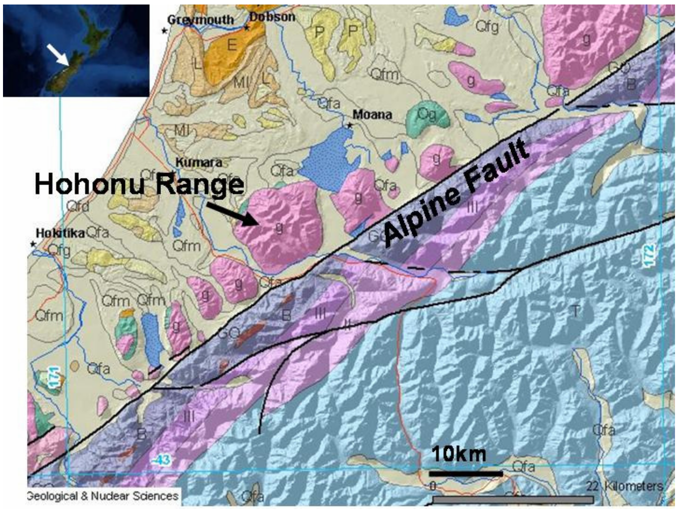

Figure 1: Location of the Hohonu Range in relation to the Alpine Fault in central Westland.

Figure 2: Examples of fragile granitic landforms on a summit ridge of the Hohonu Range, about 5km from the Alpine Fault. Stirling and Langridge undertook a reconnaissance trip to the area in Feb 2009.

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