2012 SCEC Annual Report

Fragile Geologic Features in New Zealand: New Age Constraints, and Post Earthquake Reconnaissance

Mark W. Stirling
GNS Science (Institute of Geological & Nuclear Sciences)
P.O. Box 30368, Lower Hutt, New Zealand,

Dylan H. Rood
AMS Laboratory, Scottish Universities Environmental Research Centre
East Kilbride G75 0QF UK

SUMMARY

Our SCEC funded efforts in the year 2011 have been threefold. The first focussed on gaining age control for PBRs in temperate (non-desert) environments. The case study PBR Clyde-6 is located less than 5km from the Dunstan Fault, a major active reverse fault in central Otago, New Zealand. Samples collected from a vertical profile of Clyde-6 have been used to interpret the rate of exhumation and thus an age for the PBR. The results suggest that the age at which the rock was exhumed and free to topple is ~40 ka. In other words PBRs in non-desert environments may be of similar age to their desert counterparts.

Our second activity was a visit to the epicentral area of the devastating M6.2, February 22 2011 Christchurch New Zealand earthquake to examine damaged and undamaged FGFs formed in hard volcanic rock. Strong motion records show the earthquake to have produced rock PGAs of about 1g in the epicentral region. Shag Rock, a sea-stack FGF in the epicentral region of the earthquake was intensely damaged, whereas FGFs located about 15km from the epicentral region were undamaged.

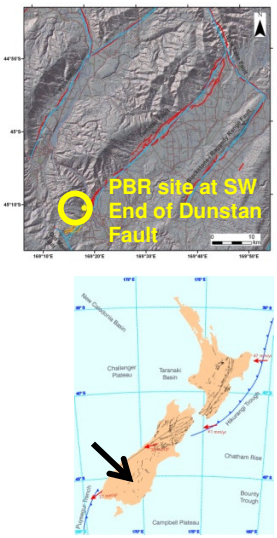
Our third activity was attending the SCEC Annual meeting and presented the poster “New age constraints for precarious landforms in New Zealand: A temperate analog for North America” (authors Stirling, Rood, Balco and Zondervan). We also went on a two day fieldtrip to the Solitario Canyon (western) side of Yucca Mountain to visit PBR sites and discuss the progress made and issues encountered during FGF studies for the ExGM project.

ACTIVITIES IN 2011

1. Dating of Clyde-6 Precariously-Balanced Rock

In recent years, studies of precariously balanced rocks (PBRs) in New Zealand have focused on age determinations of the rocks at near-fault sites. PBRs are a special class of fragile geologic feature (FGF) in which the rock is delicately balanced on a pedestal. PBRs have been a focus of research for constraining probabilistic seismic hazard (PSH) models at long return periods (e.g. Brune and Whitney, 1992). Until this year, efforts to interpret Be-10 exposure age data from PBRs in central Otago, an area with an equivalent climate to coastal central-to-northern California, have been unable to sufficiently resolve the age of any PBRs. In contrast, the year 2011 has seen considerable progress in constraining the age of the case study PBR "Clyde-6" (Fig. 1). Clyde-6 is located less than 5km from the Dunstan Fault, a major active reverse fault that has been the focus of considerable studies in recent years for seismic hazard re-evaluation of the nearby Clyde Dam. The concrete Clyde Dam is the third largest dam in New Zealand.

Figure 1. Clyde-6 PBR (left), in which the PBR is in contact with the pedestal at the narrow neck near the top of the overall tor. The red and light-colored markers on the PBR mark the position of sample sites and key geometric nodes used for photogrammetry and DEM development. The Clyde-6 PBR is located less than 5km from the Dunstan Fault (right), a major active reverse fault and the focus of seismic hazard studies for a large dam safety review.



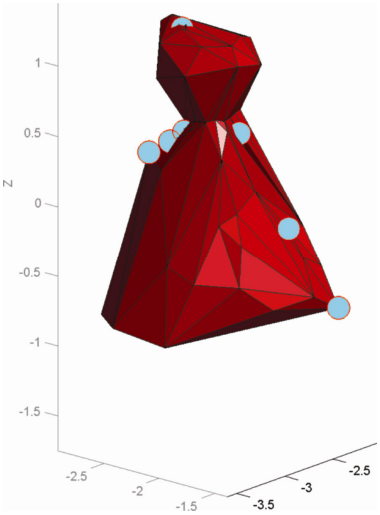


Figure 2. Sample locations on the Clyde-6 PBR DEM.

Samples collected from a vertical profile of Clyde-6 (Fig. 2) are used to interpret the rate of exhumation and thus an age for the PBR. The dating method combines measured Be-10 concentrations with a numerical model that accounts for nuclide production before, during, and after exhumation of the PBR from the subsurface (Balco et al. 2011). A three-dimensional model constructed from field-based photogrammetry conducted in April 2011 (Fig. 2) is used to correct for the shielding of cosmic rays due to the shape of the feature. The results suggest that the age at which the rock was exhumed and free to topple is ~40 ka (Fig. 3). The results also suggest that the feature sat in the subsurface for a long time period, consistent with the site being part of an exhumed Tertiary peneplain.

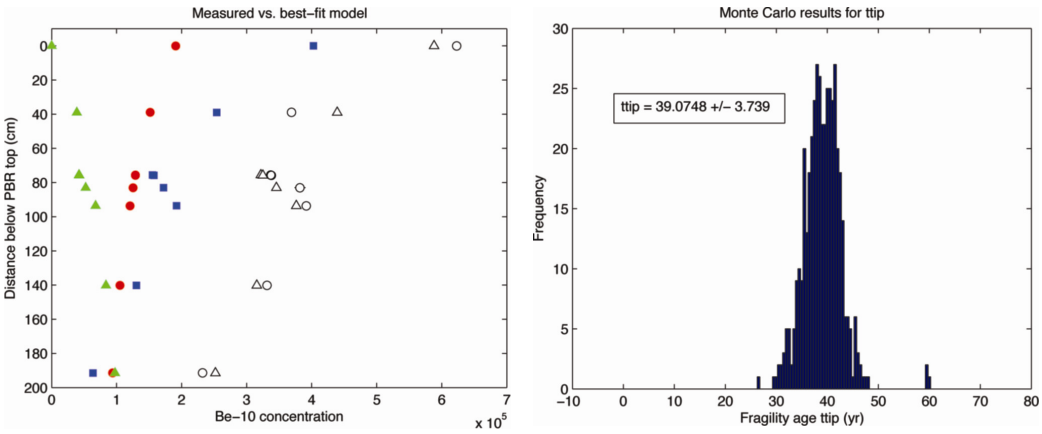


Figure 3. Be-10 concentrations of the Clyde-6 samples (left), and modeled age of the PBR in the present unstable form (right).

The ~40ka interpreted age of Clyde 6 has implications for ground motions produced by past large earthquakes on the nearby Dunstan Fault. The paleoseismic history of the Dunstan Fault (Van Dissen et al. 2007) implies that 4 to 6 near-field Mw7.1-7.5 Dunstan Fault earthquakes have occurred since Clyde-6 became precarious. Combined with the fragility of the feature (alpha~6 deg), these data suggest that ground motions in these earthquakes did not exceed 0.11-0.14g at this site. Since the Dunstan Fault and Clyde-6 are both less than 5km from the Clyde Dam, a ”Points in Hazardspace” (Abrahamson, 2008) approach to comparing the PBR to the PSH model for the Dam site (Stirling et al. in prep) will be a priority activity for completion of the Clyde Dam PSH studies this year.

The Clyde-6 study stands as a first demonstration of the age of PBRs within temperate environments (i.e. similar to central to northern California). The study shows the PBRs may be of similar age to their desert counterparts, despite the commonly-perceived differences in rock weathering in the two environments. This is an important result in the context of using PBRs for constraining PSH models at long return periods, *outside* of desert environments.

2. Reconnaissance of Damaged and Undamaged Fragile Geologic Features in Christchurch

We visited the epicentral area of the devastating M6.2, February 22 2011 Christchurch New Zealand earthquake in early April 2011 to examine damaged and undamaged FGFs formed in hard volcanic rock. Strong motion records show the earthquake to have produced rock PGAs of about 1g in the epicentral region. Of particular interest was the intense damage to Shag Rock, a sea-stack FGF in the epicentral region of the earthquake (Fig. 4). Such damage is consistent with the fragility of Shag Rock prior to the earthquake, which from local accounts was so unstable that it would periodically shed

rocks from the sides and top. In contrast, PBRs located about 15km from the epicentral region were undamaged (Fig. 5), consistent with the much lower ground motions that would have been produced there. We are currently seeking New Zealand-based funding to undertake studies of the age and prior fragility of Shag Rock.

Figure 4. Shag Rock before (left) and after (right) the M6.2 22 February 2011 Christchurch earthquake.

Figure 5. Undamaged PBRs at about 15km from the epicentral region of the 22 February earthquake.

3. SCEC Annual Meeting and Yucca Mountain Field Trip

We attended the SCEC Annual meeting and presented the poster “New age constraints for precarious landforms in New Zealand: A temperate analog for North America” (authors Stirling, Rood, Balco and Zondervan). We also went on a two day fieldtrip to the Solitario Canyon (western) side of Yucca Mountain to visit PBR sites and discuss the progress made and issues encountered during FGF studies for the ExGM project. The fieldtrip was of particular value for Stirling, who had not been there before and was unaware of the important unresolved issues surrounding the age and genesis of PBRs at the “data-rich” Yucca Mountain.

REFERENCES

Abrahamson, N. 2008. Points in hazardspace. ExGM Workshop paper, SCEC Annual Meeting 2008.

Balco, G., Purvance, M.D., Rood, D.H., 2011, Exposure dating of precariously balanced rocks, *Quaternary Geochronology*, 6, 3-4, 295-303, doi: 10.1016/j.quageo.2011.03.007. (Authors contributed equally. Listed in alphabetical order.)

Brune, J.N., and Whitney, J.W. 1992. Precariously balanced rocks with rock varnish-Paleoindicators of maximum ground acceleration? *Seismological Research Letters* 63 (1), 21.

Stirling, M.W.; Litchfield, N.J.; Rhoades, D.A.; McVerry, G.H.; and Van Dissen, R.J. 2011b. Clyde Dam seismic hazard reassessment: Phase 3: Seismic Hazard Analysis, *GNS Science Consultancy Report* 2011/243. 76 p.

Van Dissen, R., Barrell, D., Langridge, R., Litchfield, N., Villamor, P., Tonkin, P. 2007. Reassessment of seismic hazard at Clyde Dam, Central Otago: Earthquake geology field investigations and determination of Dunstan Fault rupture characteristics. 2 Volumes. GNS Science Consultancy Report 2006/147.