Landslides and ground damage during the Mw5.8 Matukituki Earthquake, 4 May 2015, central Otago, New Zealand

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GNS Science Report 2015/17
June 2015

GNS SCIENCE
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BIBLIOGRAPHIC REFERENCE

Cox, S.C.; Barrell, D.J.A.; Dellow, S.; McColl, S.T.; Horspool, N. 2015. Landslides and ground damage during the Mw5.8 Matukituki Earthquake, 4 May 2015, central Otago, New Zealand. *GNS Science Report* 2015/17. 12 p.

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ISSN 1177-2425 (Print)
ISSN 2350-3424 (Online)
978-0-478-19943-7 (Print)
978-0-478-19944-4 (Online)

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ABSTRACT

A helicopter reconnaissance was undertaken to assess ground damage and landsliding associated with M5.8 Matukituki Earthquake of 4 May 2015, which occurred 30 km northwest of Wanaka, at a depth of about 5 km. Thirty-seven earthquake-induced failures were recorded within an 800 km^2 area, principally small rockfalls of 1-1000 m^3 volume from pre-existing landslide scars, but including some newly generated bedrock failures. The total volume of rockfall is unlikely to have exceeded 30,000 m^3. Observations are consistent with empirical predictions based on earthquake-induced landsliding elsewhere in New Zealand. The observations from the Matukituki Earthquake help to delineate the lower magnitude threshold for earthquake-induced landsliding.

KEYWORDS

Rockfall, Landslide, Ground Damage, Earthquake, Matukituki River, Shotover River, Otago

1.0 INTRODUCTION

A magnitude 5.8 earthquake occurred at 2.29 pm (NZST) on 4 May 2015, with an epicentre situated at 44.5366S 168.8369E (about 30 km northwest of Wanaka) (Figure 1) at a depth of around 5 km (www.geonet.org.nz Earthquake ID 2015p332712). The national seismic monitoring network recorded a local peak ground acceleration of 11% g (NSBS at Neils Beach), but more typically 1-7% g at stations within 100 km of the epicentre. Shaking intensities were modelled to have been moderate to very strong near the epicentre and mountains of the central Otago Lakes District, using the methodology of Horspool et al. (2015) (Figure 2). Felt reports of strong shaking were received from all over the lower half of the South Island. Given its shallow depth and the accelerations recorded by seismographs, the earthquake was classed as ‘Severe’ by GeoNet, although its distance from populated centres suggested damage to property and infrastructure was likely to be minor.

Through the GeoNet programme, GNS Science maintains a rapid-response capability for landslides in New Zealand and can mobilise knowledgeable people to provide advice and gather data following any significant event. There is an associated mandate to collect observations of events that are particularly outstanding or of scientific interest. The depth and ground shaking intensities of the Matukituki earthquake were deemed to be near the threshold for triggering earthquake-induced landslides. Landslides had also recently been mapped and catalogued following two similar ‘severe’ shallow earthquakes: a M6.2 (24 April 2015) in Marlborough and a M6.0 (5 Jan 2015) in the Wilberforce River area (Southern Alps). These earlier earthquakes, however, occurred in areas where the bedrock is predominantly greywacke sandstone and argillite. The Matukituki earthquake occurred where the bedrock is metamorphic schist rock, thereby providing the opportunity to compare and contrast the ground-damage behaviour of schist versus greywacke terrain during similar shaking intensities.

Given this scientific interest in the earthquake effects, GNS Science initiated an immediate science response to establish the nature, extent and location of any landslides triggered by the earthquake. With over 100 mm of rain forecast to start within 48 hours, Sally Dellow (GNS Avalon) organised a team of geologists to be deployed as quickly as possible. Simon Cox (GNS Science, Dunedin) and Sam McColl (Massey University) were at Glenorchy undertaking fieldwork at the time of the earthquake. The following morning (5 May 2015) they met Trevor Andrews (Emergency Management Officer QLDC) and Nick Nicholson (Heli Glenorchy). In rapidly deteriorating weather, they undertook an aerial inspection of the north and western epicentral area from 0930-1100. Meanwhile David Barrell (GNS Science Dunedin) was mobilised from Dunedin, and joined Simon and Nick for a second flight of the east and southern epicentral area during the afternoon (1245-1415).

Features observed and photographed during the reconnaissance flights, were subsequently checked against historic satellite and aerial imagery, then mapped into a GIS dataset. This immediate report provides an outline of ground damage and landslide activity attributed to shaking during the M5.8 Matukituki earthquake.

2.0 SETTING

The epicentre of the Matukituki earthquake was located in mountainous topography ~ 20 km south-east of the main divide of the Southern Alps, in Mt Aspiring National Park (Figure 1 and Figure 2). The topography (within a 50 km epicentral radius, herein referred to as the 'earthquake region') is typically steep, with a mean slope of ~ 25° and with 25% of slopes > 36°, and high relief, having a maximum relief of ~ 3000 m and average local (1 x 1 km) relief of ~ 480 m. The steep, high-relief topography partly reflects a history of intense glacial, periglacial, fluvial, and hillslope erosion of the tectonically-uplifted terrain. Cirque glaciers and ice-aprons cover approximately 4% of the earthquake region and are restricted to elevations mostly above ~1500 m a.s.l. Formerly, glaciers extensively covered this area (Barrell, 2011; Turnbull 2000), including major valley glaciers which produced deep, steep-sided valleys, some of which are now occupied by lakes (e.g., Wanaka and Hawea). The modern climate is conducive to intense freeze-thaw weathering, and seasonal snowfalls.

Local bedrock is greyschist with minor greenschist – metamorphosed sandstone, mudstone and volcaniclastic rock of the Rakaia and Caples Terrane (Turnbull, 2000). These rocks have an internal weakness formed by mica growth (schistosity and foliation) and sparse fractures (joints). The shape of hillslopes is strongly dominated by foliation-controlled dip-slopes and joint-controlled scarp-slopes.

Slopes in the earthquake region display numerous slope instability features including; small landslide scars, active scree slopes, and evidence of deep-seated slope failures within the schist bedrock (e.g., Turnbull, 2000; Cook et al., 2013; Figure 1). Documented historical landslides include historical debris-flows (e.g., McSaveney and Glassey, 2002), large fluvio-mass movement complexes (e.g., Cox et al., 2014), and very large rock falls (e.g., 2007 Young River landslide; Bryant, 2010). Pre-historic large landslides have also been documented, such as the ~600 M m^3 early-Holocene Lochnagar landslide (Figure 1) located 18 km west from the epicentre (Sweeney et al., 2013), and the ~22 M m^3 early-Holocene Hillocks rock avalanche in Dart Valley (McColl and Davies, 2011; Figure 1).

3.0 METHOD

3.1 LANDSLIDE IDENTIFICATION

The Matukituki earthquake region, and the upper Shotover catchment in particular, contain numerous landslides (Figure 1) and fresh erosion scars that are regularly activated. This can make it difficult to distinguish new 'earthquake-induced' landslides from pre-existing features that may have been present in the landscape for a number of years. Key indicators of new activity that can be seen in the field include: fresh dirt or dust coatings on new landslides; disrupted green vegetation within new landslide debris; discoloured, turbid water where material has recently fallen into waterways; presence of snow or erosion runnels on old landslides.

3.2 LANDSLIDE RECORDING

Approximately 500 digital photographs were taken during the reconnaissance flights. Camera clocks were synchronised against GPS clocks prior to take-off, enabling photographs to be located along the recorded flight tracks then easily positioned (geotagged). Following the flight, these photographs were compared with vertical aerial, Google Earth and other available satellite imagery. This enabled clear distinction of those landslides that had already been present prior to the earthquake and enabled the scale of new material that may have fallen during the earthquake to be approximated. Landslide maps generated on hard copy sheets (1:250,000 and 1:50,000) during the flight, or digitally on an iPad synced with the helicopter GPS position, were transferred into ArcGIS database for verification.

Landslide activity and ground damage were recorded as a point (XY) dataset, located with a horizontal precision of approximately ±200 m. Landslides and rockfalls were classed as either 'new' or 'reactivated'; with a logarithmic volume estimate (1-10 m^3, 10-100 m^3, 100-1,000 m^3, or 1,000-10,000 m^3). The completeness of this catalogue was partially limited by the nature of the reconnaissance activity. Landslides were recorded where they could be observed along the flight path, but the flights paths did not cover the entire area of intense shaking, in part due to the weather and flying conditions. The area north and east of the Matukituki River in particular, was not examined. The number of observations should therefore be considered to represent a minimum. Many of the landslides involve reactivation of old features, so we consider that the estimate of mass-movement volume is likely a maximum. Given the occurrence of intense rainfall on 6 May 2015, which may have produced further mass movements and obscured the effects of the earthquake, there are no plans to further extend the landslide survey.

4.0 RESULTS

The reconnaissance survey identified 37 mass movements and one site of especially intensive ground damage (ridge renting/cracking) (Figure 2). Of the 37 mass movements, 27 were reactivations of existing landslides, and 10 appear to be sites of new activity. The observed landslides were restricted to within an area of 800 km^2, with the most distal landslide located 38 km S-W from the epicentre. First-time failures were restricted to an epicentral distance of 16 km.

Relatively small rockfalls, or collapse of loose debris into gullies, were the most common (33 of 36) features identified (e.g., Figure 3). These almost invariably occurred from steep slopes (>40º). Fifteen rockfall volumes were estimated at 1-10 m^3; 12 at 10-100 m^3; 6 at 100-1000 m^3; and 1 about 1,000-10,000 m^3. The largest rockfall occurred from near Homestead Peak into the Glacier Burn, 12 km from the epicentre on the other side of Matukituki Valley. It produced a dust cloud that was captured by a webcam at the Whare Kea Chalet (www.wharekealodge.com) a farther 12 km to the north (Figure 4).

The estimated total volume of rockfall produced by the earthquake in the area observed during the flight was about 30,000 m^3. Relative to earthquake-induced landslides documented from other earthquakes in New Zealand, this is a very small volume. It is feasible that one or more significant landslides away from the area of the flight observations could equal or exceed this volume.

Riverbank collapse and lateral spreading were observed at two locations. At Glenfinnan Bluff, Matukituki Valley, a small section of the riverbank and Mt Aspiring road translated towards the river, involving approximately 100-1,000 m^3 of material (Figure 5). A small section of riverbank collapsed just upstream from Sharks Tooth Hut in the upper Poolnoon Burn (Middle Branch) involving about 10-100 m^3.

Ridge-renting and cracking occurred on the southeast ridge of Duries Peak (1645m), Poolnoon Burn, about 15 km south of the epicentre (Figure 6). Earthquake waves appear to have been amplified by the ridge and cracked open about 150 x 100 m of the existing rock fractures. Some of these may have been gravity-related features present prior to the earthquake.

A landslide on a ridge on the north face of Mt Campbell appears to have moved ~4 m downslope as a result of the earthquake, before coming to a halt (Figure 7). The landslide was visible as an incipient feature prior to the earthquake, in satellite imagery, but appears to have accelerated and translated downslope as a result of the shaking.

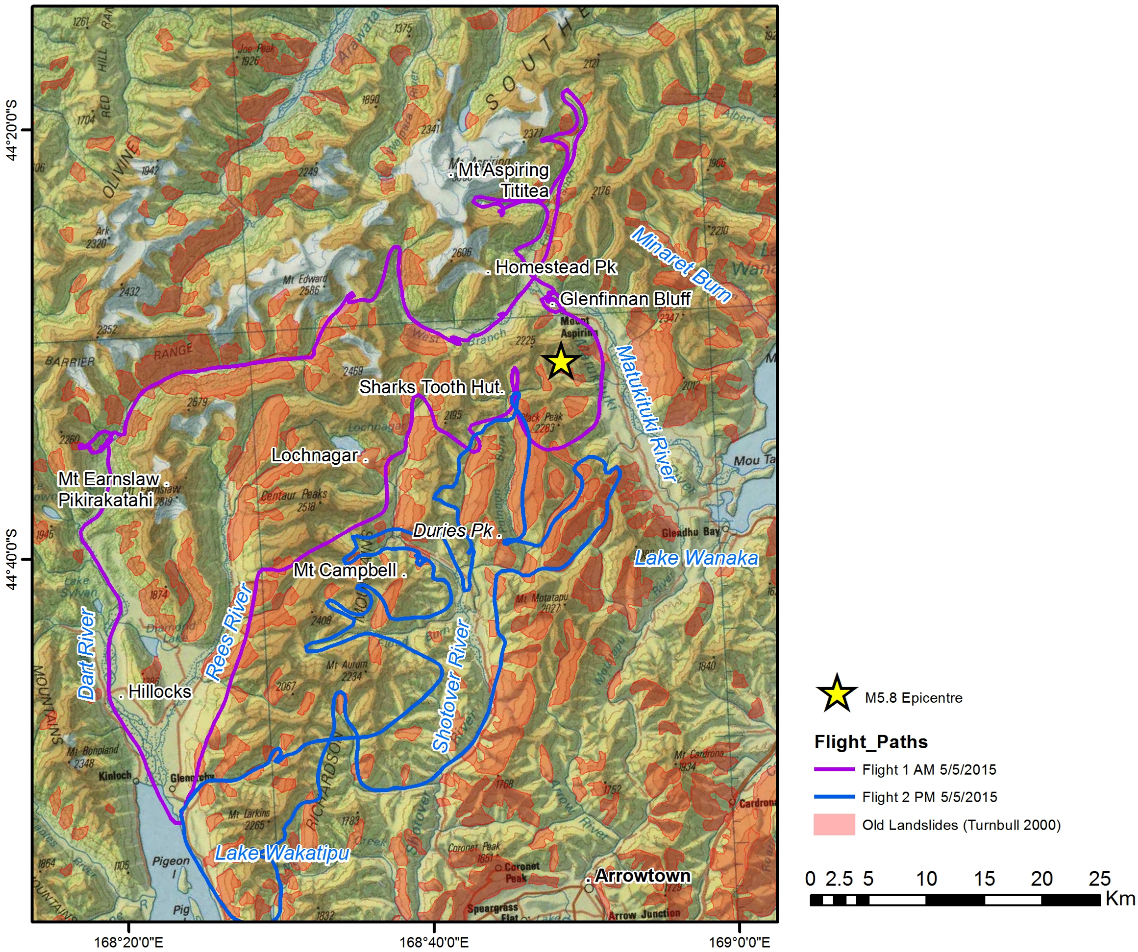

Figure 1 Location map of the 4 May 2015 M5.8 Matukituki Earthquake region, the rapid response aerial reconnaissance flight routes, and old, pre-earthquake landslides (shaded red) mapped by Turnbull (2000) for the QMAP 1:250,000 database.

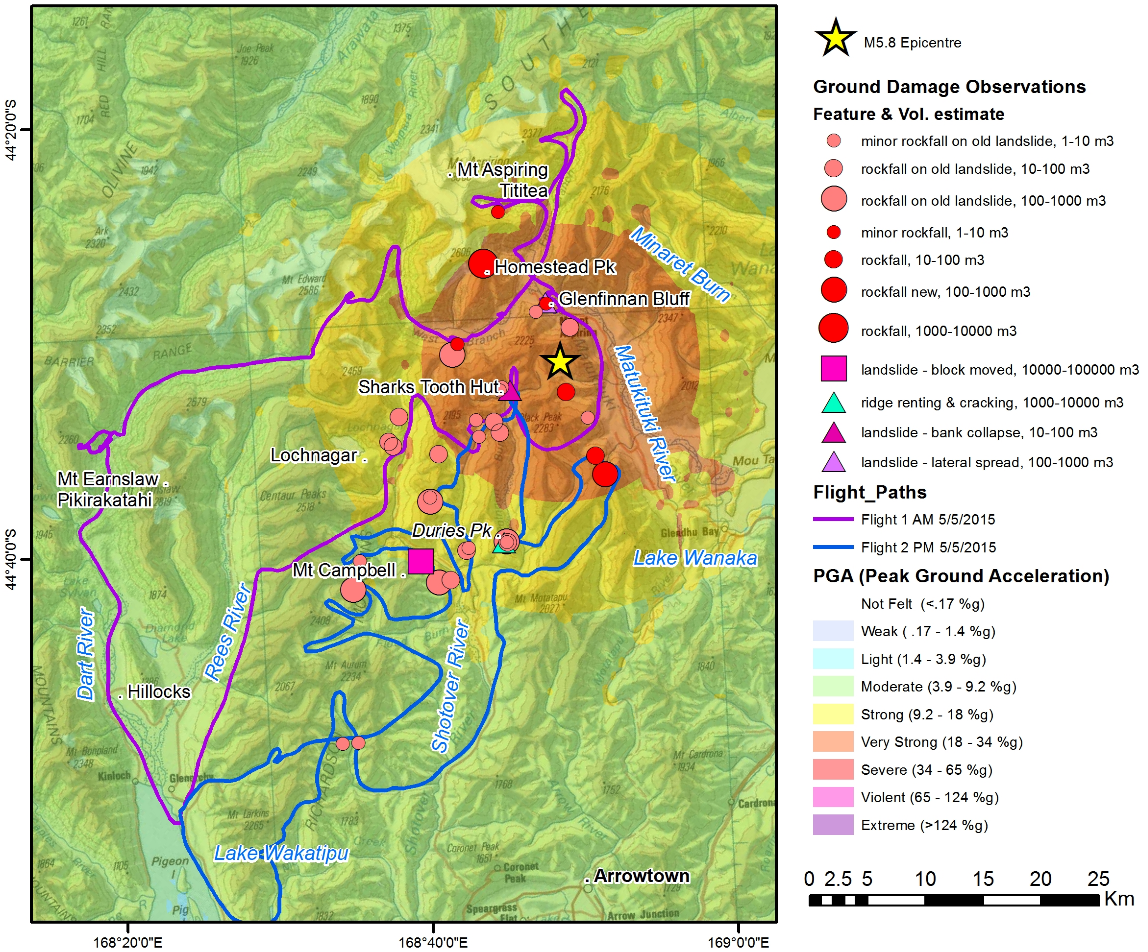

Figure 2 Map of rapid response aerial reconnaissance flight routes and new earthquake-induced landslide locations in relation to the predicted shaking intensity (%g) and the 4 May 2015 M5.8 Matukituki Earthquake epicentre.

Figure 3 Aerial view of reactivated landslide on the east face of Duries Peak 1645 m, Poolnoon Burn, about 15 km south of the epicentre. Notice the fresh brown dirt/dust confirming it is a recent event. Photo: Simon Cox, GNS Science/GeoNet, 5 May 2015.

Figure 4 Webcam view of dust clouds, to left of the snowy Homestead Peak generated by a rockfall into the Glacier Burn (about 15 km northeast of the epicentre) and in the far distance from peaks above the West Matukituki into Downs Creek. Photo: http://www.wharekealodge.com/nz/chalet-webcamSW/.

Figure 5 Aerial view of the Mt Aspiring road where it traverses Glenfinnan Bluff. The brown track of a fresh rockfall can be tracked down to the road in centre photo, where two orange road cones mark its passage to the river. Cracks have opened in green grassy slopes above the road (right) where the back has spread out into the river. Photo: Simon Cox, GNS Science/GeoNet, 5 May 2015.

Figure 6 Aerial view of freshly opened fractures and renting of a ridge on Duries Peak 1645 m, Poolnoon Burn, about 15 km south of the epicentre. Photo: Simon Cox, GNS Science/GeoNet, 5 May 2015.

Figure 7 Aerial view of a relatively low-displacement landslide located on a ridge on the north face of Mt Campbell. The landslide translated ~4 m downslope before coming to a halt. About 18 km south of the epicentre. Photo: Simon Cox, GNS Science/GeoNet, 5 May 2015.

5.0 DISCUSSION

Five classes of earthquake-induced landslide (EIL) ‘opportunity’ were recognised by Hancox et al. (2002), with the term *opportunity* relating to the occurrence of seismic shaking strong enough to trigger landslides. Classes of very-low, low, moderate, high, and very high were derived using EIL/Magnitude Moment relationships in New Zealand together with an approximate Magnitude Moment/Peak Ground Acceleration (PGA) relationship range.

Based on observed and modelled shaking, the M5.8 Matukituki Earthquake appears to have been at the transition between very-low and low opportunity for stiff soil sites or rock sites mantled by more than 3 m of soil (“Class B” sites following the New Zealand Loadings Standard NZS4203:1992). Based on its magnitude and PGA, the Hancox et al. (2002) suggest the earthquake-induced landsliding should lie between (i) *very small rock and soil falls on the most susceptible slopes*; and (ii) *small landslides, soil and rock falls may occur on more susceptible slopes (particularly road cuts and other excavations), along with minor liquefaction effects (sand boils) in susceptible soils*.

Observations from the reconnaissance flight concur reasonably well with the observations of Hancox et al. (2002). No very large or potentially damaging landslides were triggered by this earthquake. Most failures were from reactivated landslide scars or colluvium slopes, rather than new sites. The volumes of both individual and total rockfalls were very small – being predominantly rock and debris falls from steep slopes (>40 degrees). The observed rockfalls were restricted to within an area of 800 km^2 and maximum epicentral distance of 38 km. The empirically-derived average and upper bound of the area affected by landslides for a M5.8 earthquake in New Zealand are 73 km^2 and 600 km^2, respectively (Hancox et al., 2002). Given that the area of landsliding observed for the Matukituki earthquake does not include the topography north and east of the epicentre, the total area affected is likely to have been somewhat larger than 800 km^2. The maximum epicentral distance, predicted by Hancox et al. (2002) for a M6 earthquake is 30 km, which is slightly less than the 38 km maximum epicentral distance observed here.

The slightly larger than expected maximum epicentral distance and size of the area affected probably reflects the number of unstable old landslide scarps (i.e., Class B soil types of Class A rock), steepness of topography in the area, and the presence of unstable schist rock masses in an alpine environment. The catalogue of observations from the Matukituki Earthquake may therefore be useful to help delineate the position of the lower magnitude threshold for earthquake-induced landsliding in this type of terrain. In doing so, however, it may be necessary to consider the distribution against the orientation of schistosity, the presence of dip-slopes and scarp-slopes, and the area northeast of the Matukituki River that was not covered by the reconnaissance.

6.0 CONCLUSIONS

1. An aerial reconnaissance survey of the 4th May 2015 Matukituki Mw5.8 earthquake, indicated landslides and ground damage occurring within an area of 800 km^2, and within a maximum epicentral distance of 38 km.
2. Observations were made of 37 mass movements and 1 site of intense ground damage. The most common mass movements were rock and debris falls and slides, with a minor bank collapse and a lateral spread also being observed. Most (27 of 37) of the mass movements were reactivations of existing landslide masses, and the total volume of rock and debris fall estimated to have been mobilised by the earthquake was ~ 30,000 m^3.
3. The area affected, number of mass movements, and the volume estimates provided here are likely to be minimum values because the area to the north and east of the epicentre could not be investigated due to adverse weather. The size of the landslides and severity of ground damage observed were commensurate with other landslide-inducing earthquakes of this magnitude in New Zealand. However, the extent (area affected and maximum epicentral distance) of landsliding is slightly higher than expected. We suggest that this likely reflects a high susceptibility of the area to rock and debris fall, resulting from the combination of steep topography and weathered (fractured) surficial schist rock masses and regolith. This is supported by the observation that most of the observed mass movements were reactivations of existing failures, and first-time failures were restricted to an epicentral distance of 16 km.
4. There are two important caveats that should be considered when placing observations of this work in a national context. Firstly, the landslide distribution is likely to have been partially influenced by prominent scarp-slopes and dip-slopes that have formed throughout the epicentral region on schist foliation, resulting in a bimodal distribution of steeper and shallower slopes, respectively. The dataset may also be incomplete for the area northeast of the Matukituki River.

7.0 ACKNOWLEDGEMENTS

We have appreciated the assistance of: the GeoNet Team and duty seismologists; Nick Nicholson (Heli Glenorchy); Trevor Andrews (Queenstown Lakes District Council); Phil Glassey (GNS Science Dunedin); Michael Goldsmith (Otago Regional Council); James Brasington and Niall Lehane (Queen Mary University of London). Satellite imagery delivered via Worldview II and Google Earth was also very useful. Funding was provided through the New Zealand Hazards Platform and GeoNet project (http://www.geonet.org.nz/) landslide immediate response function, supported by the Earthquake Commission and the Ministry of Business Innovation and Employment. This report was reviewed by Mauri McSaveney, Jon Carey and Phil Glassey.

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