Job Number: 460W6303

File Number: LD8 (NZTopo50-BX24)/941-947

GNS SCIENCE IMMEDIATE REPORT

DATE: 2 March 2011

SUBJECT: Report on Landslide Reconnaissance Flight on 24 February 2011 following the M_w 6.3 Christchurch Earthquake of 22 February 2011

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1. Introduction

The M_w 6.3 Christchurch earthquake at 12:51 (NZST) on 22 February 2011 caused widespread damage and multiple fatalities in the Christchurch central business and Lyttleton. The GeoNet website *(www.geonet.org.nz)* gives the earthquake location as 43.60° S, 172.71° E (within 5 km of Lyttleton), at a depth of 5 km. Large rock falls and landslides were reported at Lyttleton and in the eastern suburbs of Sumner and Redcliffs, and along the Summit road east of Dyers Pass, some of which extensively damaged or destroyed houses, and resulted in at least four or possibly five fatalities.

An initial helicopter reconnaissance flight over the landslide damaged area was undertaken in the afternoon of 23 February 2011 by Richard Jongens, Jane Forsyth, and Delia Strong from GNS Science Dunedin, accompanied by University of Canterbury staff Mark Quigley and Marlene Villeneure. Following that flight the key findings on earthquake-induced landslide damage in the earthquake-affected area were (from Jongens et al. 2011):

(1.) Large tension cracks extending beyond the cliff edge (up to 60 m) between Monks Bay-Sumner and to a lesser extent on the east side of Scarborough pose a significant hazard to residents.

(2.) Many precariously placed rocks and unstable slabs above the Lyttleton township, Evans Pass Road (Lyttleton side), above Rapaki Bay and above Living Springs, have the potential to fall in a significant aftershock or heavy rain.

Prior to that flight, Stuart Read (Acting Section Manager Active Landscapes, and Manager of the Landslide Response to the Christchurch earthquake) arranged for a GeoNet Response reconnaissance flight over the Lyttleton–Sumner area to be undertaken from Paraparaumu. That flight was carried out on 24 February by GNS Science Lower Hutt staff Graham Hancox and Nick Perrin to map and photograph landslides, and Russ Van Dissen, whose main interest was to look for possible surface fault rupture in the Port Hills epicentral area.

This report provides initial information from the landslide reconnaissance flight on Thursday 24 February 2011. It includes an aerial assessment of the distribution, nature, effects, and relevance of landslides triggered by the 22 February earthquake. A number of photos are included to illustrate the landslides that occurred and the damage they caused.

2. Reconnaissance flight narrative and track log

On Thursday 24 February 2011 the landslide response aerial reconnaissance team flew from Paraparaumu to Kaikoura Airport in a Kapiti Aero Club Cessna 172 (11:00-12:15 hrs). At Kaikoura we transferred to a R44 helicopter (Kaikoura Helicopters) for the flight to Christchurch to undertake a comprehensive flight (with the door off) over the many landslide affected areas, after which we flew back to Kaikoura (12:47-~17:15 hrs, includes 3 short stops). We then returned to Paraparaumu in the Cessna 172 (17:15-18:30 hrs).

We carried out an extensive reconnaissance flight over the epicentral area of the M_w 6.3 earthquake on Tuesday 22 February 2011 to observe and photograph rock falls and landslides triggered by the earthquake. The main areas inspected include Sumner, Redcliffs, Lyttleton, Port Hills-Summit Road, Governors Bay, Quail Island, Diamond Harbour, and Godley Head and Adderley Head at the entrance to Lyttleton Harbour. Figure 1 is a GPS track-log of the flight (larger version at back of report). Unfortunately we were unable to fly over the Mount Pleasant area to the west of Redcliffs, which was also affected by landsliding, because that area was within the flight exclusion zone in place at the time.

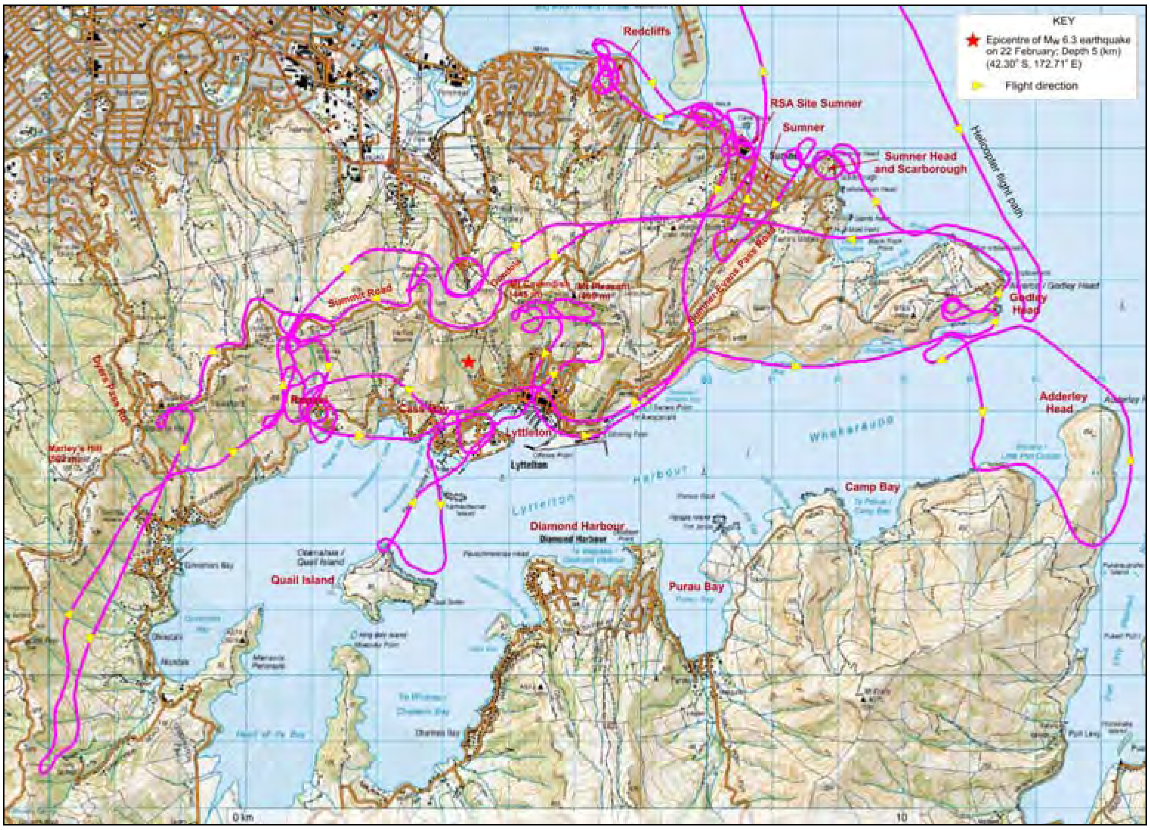

Figure 1. GPS track log and directions of landslide reconnaissance flight on 24 February 2011.

3. Results of the Reconnaissance Flight

The helicopter over flight on Thursday 24 February enabled more than 500 high resolution images to be taken of almost all of the major landslide and rock fall sites under much better light conditions than would have been possible the during the initial helicopter over flight by GNS staff on 23 February (Jongens et al. 2011). The photos obtained on 24 February include both distant and close-up aerial views of rock fall source areas and debris, as well as the damage to houses and other buildings, some of which were totally destroyed by massive basalt boulders, some as large as cars. Efforts were made to obtain good photos of houses damaged by rock falls, including some sites where possibly five fatalities due to rock falls were reported on TV One News the day after the earthquake. All of the photos taken on the flight have been placed in the GNS I:Drive\Hazard Platform\22 February Aftershock folder.

3.1 Landslide affected area

The reconnaissance flight clearly showed that the areas most affected by landslides (dominantly rock falls, debris falls, debris slides in the terminology of Cruden and Varnes, 1996) are in the urban areas of Sumner to Redcliffs, Lyttleton, Cass Bay, and Rapaki, and the Summit Road and Sumner-Evans Pass Road on the Summit ridge on the northern side of Lyttleton Harbour. This main landslide affected area north of Lyttleton Harbour was quite well defined and only a few very small failures were noted on steep coastal cliffs to the south, on the northern side of Quail Island, Diamond Harbour and Camp Bay areas out toward Amberley Head. These areas and other sites of interest are shown on the flight log map (Figure 1). These findings are consistent with observations reported by Jongens et al. (2011).

On the south side of Lyttleton Harbour from Gebbies Pass to Charteris Bay and Diamond Harbour to Purau Bay there are only minor rockfall on steep cliffs and road cuttings. The observations by ground parties indicate that there is little landsliding of significance on the south side of the harbour compared to what occurred on the northern side. Damage to houses and roads on the south side of Lyttleton Harbour is apparently minimal with roads having only minor cracks on downslope sides facing the harbour, and few impact craters from minor rock falls (pers. comm. Richard Jongens). This is consistent with our observations on the helicopter reconnaissance flight on 24 February.

To the north of Christchurch a few very small new slope failures (mostly fresh-looking scars on old landslides) were noted on the coastal cliffs between Motunau Beach and Hurunui Bluff, about 60 to 80 km north of the earthquakes epicentral area near Lyttleton. Based on the GeoNet felt reports these small failures are within the ~MM4-5 intensity zone, and may also have been triggered by the 22 February 2011 earthquake, but this is not certain.

From our observations and photos taken on the 24 February helicopter flight approximately 170 landslides that were clearly triggered by the earthquake have been located and plotted on NZTopo50-BX24 topographic base map to produce an initial landslide distribution map for the 22 February earthquake (Figure 2). This map also shows the main area (~30 km^2) affected by landsliding, and the locations of selected landslide photos which illustrate the nature of the landslides and the damage that they caused (Photos 1 to 33 at back of report). Figure 3 shows both the main area affected by landslides triggered by the earthquake and the estimated total area that appears to have been affected (~150 km^2).

3.2 Geology and geomorphology of landslide affected area

The rocks forming the 400-500 m high ridge, slopes, and sea cliffs on the northern side of Lyttleton Harbour (in the Port Hills, Summit Road, Sumner and Redcliffs areas) belong to the *Lyttelton Volcanics Group* rocks of late Tertiary (Miocene) age, and are about 10–12 million years old (Sewell et al. 1992). These volcanic rocks comprise layers of hard, jointed basaltic and trachytic lavas with numerous dykes, interbedded with breccia, agglomerate (coarse angular gravel) and compact sandy tuff beds. The volcanics are mantled with surficial loess soils (wind-blown sand and silt) typically up to 1 m thick and locally 5 m or more.

The volcanic rocks in the Lyttelton area are relatively strong, and the interbedded scoria and tuff layers are softer but compact. Most lava flows in the Lyttelton area are closely and irregularly jointed, resulting in a blocky rock mass that periodically releases individual or multiple blocks of rock that roll down the face and accumulate as a talus deposit at the base of slopes (Yetton 2002). Many natural slopes around Lyttelton harbour stand at relatively steep angles, forming near-vertical cliffs on many nearby coastal slopes (such as those around Diamond Harbour and Quail Island) which are internally supported by strong interbedded lava flows (Brown and Weeber, 1992; Sewell et al. 1992).

The steep coastal cliffs around Lyttleton, and extend further inland in the suburbs Sumner and Redcliffs areas are remnants of an old (~9,000 years B.P.) sea cliff. These near vertical (~75–85°) cliffs are, and are typically 15 to 30 m high and up to ~70 m high in some places. The old sea cliff has been modified by quarrying in several areas, including the major rock quarries located at Redcliffs and Sumner (Brown and Weeber, 1992), where basalt was quarried to construct the causeway across McCormacks Bay (Figure 1).

Slopes on the northern and southern sides of the Summit Road ridge north of Lyttelton, which extends from Mt Pleasant (499 m) at the eastern end near Evans Pass, to Marley's Hill (502 m) at the western end near Dyers Pass Road are steep to very steep. The upper slopes near the ridge crest are in places very steep to near vertical (~50–75°) extend 500 to 1500 m down steep (~35-30°) and moderately steep (~30-20°) slopes to the urban areas of Lyttleton, Cass Bay, and Rapaki, and northern shore of Lyttleton Harbour (Figure 2).

3.3 Evidence for active faulting

No evidence for surface fault rupture was seen in the Port Hills area covered by our flight path (Figure 1). Several low altitude passes were made over the Port Hills region in the epicentral area and we saw no evidence for surface fault rupture (specifically we spent a fair bit of time over the Summit Road area – over about a 1 km swathe either side of road – between about Evan Pass in the east to Witch Hill Reserve and to Mt Vernon in the west. We did not fly along the northern base of the Port Hills because (1) this was restricted air space; and also because (2) the earthquake epicentre, as we understood it, is located to south of that between Lyttelton and Sumner, so that was where we focused our attention with regards to looking for possible surface fault rupture.

4. Comments and conclusions on landslides and effects

(1) The 22 February Christchurch earthquake triggered a relatively large number of rock falls and debris falls on steep coastal cliffs from Godley Head to Sumner and Redcliffs about 3 to 7 km north and east of the earthquake epicentre, and on the steeper southern slopes of Lyttleton Harbour, and along Summit and Sumner–Evans Pass roads, and on the Mt Vernon–Mt Pleasant ridge 300 to 500 m above Lyttelton, within 3 km of the epicentre. Most of the failures occurred on steep to near vertical (~35–75°) coastal cliffs, ridges, and unsupported road cuts and excavations for buildings and quarries, and steep natural slopes. All of these areas have high susceptibility to earthquake-induced slope failure.

(2) About 170 landslides occurred in the main area affected by landsliding, spread over ~30 km in the epicentral area. On the south side of Lyttelton Harbour only a few small, non damaging slope failures on steep cliffs and road cuttings were seen within 3–8 km from the epicentre (Figure 2). This distribution is consistent with that reported earlier by GNS Dunedin staff (Jongens et. al. 2011). The total area affected by landslides triggered by the earthquake is estimated to be about 150 km^2 (Figure 3).

(3) Most of the earthquake-induced slope failures are rock falls from the steep coastal cliffs, especially the old sea cliff and former quarry areas at Sumner and Redcliffs, and some in the Mount Pleasant area, where relatively large (estimated to range from 10s to 100s of cubic metres, and a few of several thousand cubic metres) of basalt boulders up to several metres across cascaded from the ~30-70 m high cliff faces on to roads, parkland, and areas behind buildings, and residential houses.

(4) Some rock falls caused substantial damage to houses and other buildings built very close (~5–15 m) to the cliff face, and some of these houses were totally destroyed by rock falls (Photos 4 to 25). The runout hazard zone from cliff failures was typically limited to an area about 5–30 m out from the base of the cliff (or about ½ -1 times the cliff height). Two or possibly three fatalities in the Sumner-Redcliffs area have been attributed to rock falls (Photos 6 and 17), and another two fatalities due to rock falls were reported on walking tracks above Lyttleton (Photo 29). The potential for further rock falls in all of the damaged areas during aftershocks is thought to be very high. Any new failures could result in more damage to houses and injuries to occupants, and possibly further fatalities.

(5) There were also many falls of multiple and individual boulders up to 1 or ~2 metres across on to roads, especially on the very steep south-facing slopes on the north side of Lyttleton Harbour, and above the Sumner-Evans Pass Road and Summit Road. Many boulders hit and damaged houses (Photos 5, 8, 9). In one case a car-sized boulder travelled ~600 m laterally and 350 m vertically down a steep slope and went through a house at Rapaki (Photos 26 to 28), which was fortunately unoccupied at the time. On the northern side of Lyttleton harbour the boulder fall hazard runout zone extended many hundreds of metres downslope from the source areas, typically on lava bluffs near the ridge crest.

(6) The intensity of rock falls on a short section of the Summit Road in The Tors area (Figure 2) was particularly noteworthy, with the road completely covered by large rocks over a length of several hundred metres (Photos 30 and 31). The other intense rockfall area was on the south side of Evans Pass where a tanker was stopped by rocks on the road. Elsewhere the rock falls are more scattered.

(7) Several of the major rockfalls on the cliffs at Sumner and Redcliffs exhibit significant crown cracking along the cliff edge, especially in the areas of Clifton Terrace, Kinsey Terrace, Glendevere Terrace (Photos 14, 22, and 23). In these areas there is potential for further rockfalls from the cliff edge, especially during large aftershocks. A similar hazard exists along the edge of the cliff top at Sumner Head, where extensive incipient cracking has developed in front of houses in Searidge Lane on Taylors Mistake Road, Scarborough (Photos 2 and 3). GNS Science staff and other geotechnical experts are currently assessing the stability of these areas on the ground.

(8) Overall, the landsliding triggered by the 22 February Christchurch earthquake was spread over a relatively small area. The main area affected by landslides covers about 30 km^2, centred on the Summit Road ridge of the Port Hills north of Lyttleton Harbour. A few small rock and debris fall were also noted on steeper terrain to the west and south of the main area of landslides, and the total area affected by landslides triggered by the earthquake could be approximately 150 km^2 (Figure 3). However, as shown in Figure 4, these areas are consistent with, but towards the lower bound of the areas affected by landsliding during other historical earthquakes of similar magnitude in New Zealand (Hancox et al. 1997, 2002).

(9) On a comparative basis the landslides triggered by the earthquake are also somewhat smaller than those caused by most large (M 7 or greater), shallow earthquakes in New Zealand. Unlike the 1968 M_w 7.2 Inangahua earthquake, when large ridge-crest rock falls were almost continuous on some limestone bluffs, no large (10^5 m^3) or very large (10^6 or > m^3) landslides were triggered by the 22 February earthquake, during which the rock falls mainly occurred in patches on steep slopes or isolated falls of loose, joint-bounded blocks, some as large as small cars off protruding bluffs of basalt lava.

(10) Based on recent studies of historical earthquake-induced landsliding in New Zealand (Hancox et al. 2002, Dowrick et al. 2008) the shaking intensity indicated by the size and intensity of the rock falls is indicative of about intensity MM 8 shaking in the main (epicentral) area of landsliding, and appears to have reached possibly MM 9 on the ~20–50 m high cliffs in the Sumner and Redcliffs areas.

(11) The cliff tops and low ridge crests at Sumner, Redcliffs, and Mount Pleasant appear to have been more strongly shaken, probably due to topographic amplification and focussing effects. Many houses on the low ridges and headlands in these areas were very badly damaged, suggesting that the shaking intensity may have reached at least MM 9 locally (pers. comm. Chris Massey). The greater shaking damage to houses on the ridges compared to houses in low level areas was also clearly evident from the air (Photo 8a). South of Lyttleton Harbour the intensity indicated by a few small isolated rock falls reduces to about MM 5–6.

(12) Despite the relatively smaller size of rock falls triggered by the 22 February earthquake, the effects and damage that they caused was very significant because they occurred within an urban area, close to and directly above houses and other buildings. Further damaging slope failures could occur in some areas during the ongoing aftershocks. The risk of further rock falls is highest where there is loose rock on the slopes that failed, especially where there is cracking along the edge of the cliff face.

5. References

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Yetton, M.D., 2002. Report on the geotechnical zonation of land within and adjoining the deferred LHA Planning Zone, Upper Heathcote Valley. *Report Reference 1371 - prepared for Christchurch City Council, May 2002.*

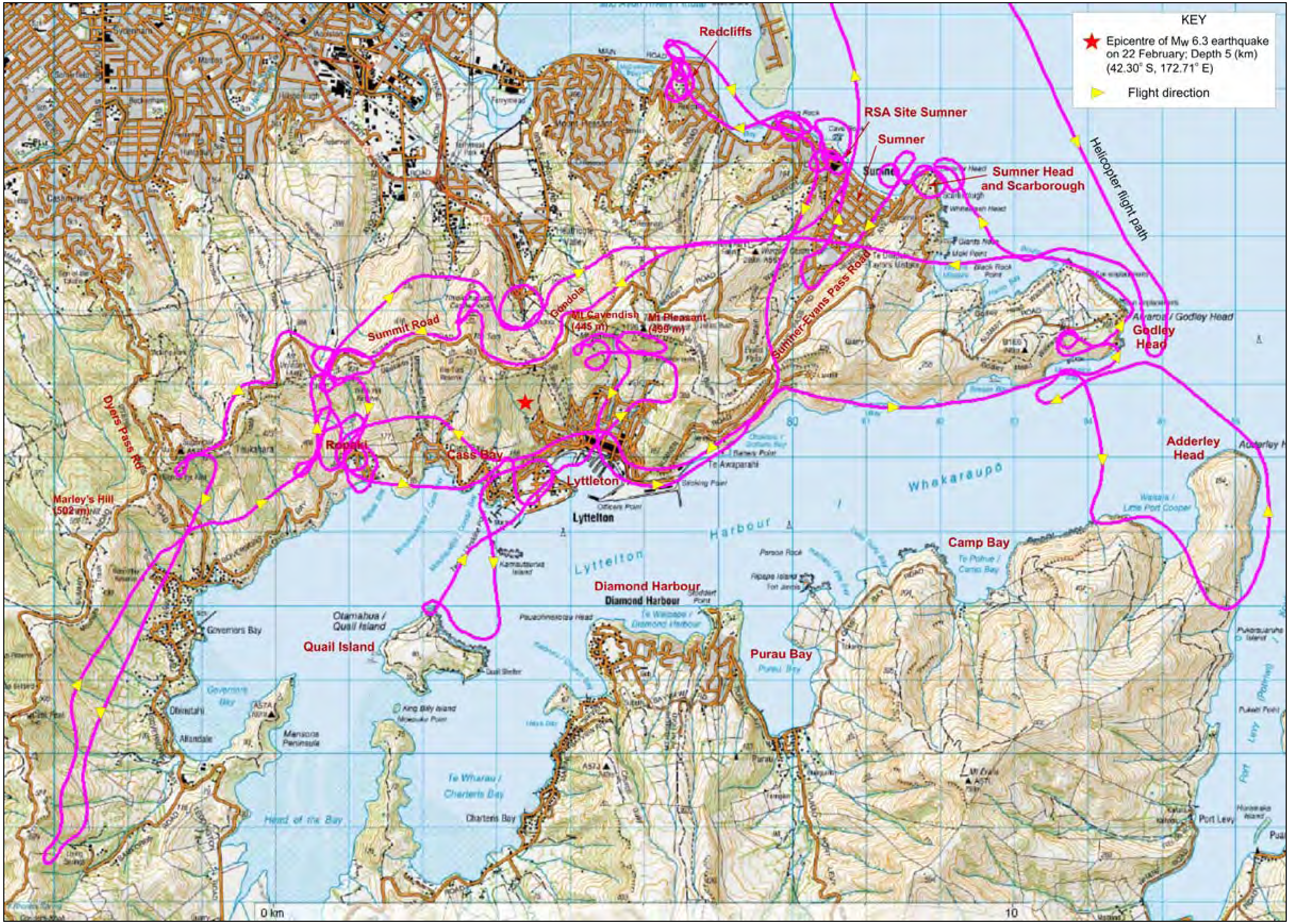

Figure 1. GPS track log and directions of the landslide reconnaissance helicopter flight on 24 February 2011.

Figure 2. Map showing the distribution of landslides triggered by the 22 February earthquake, the main area affected, and locations of landslide photos.

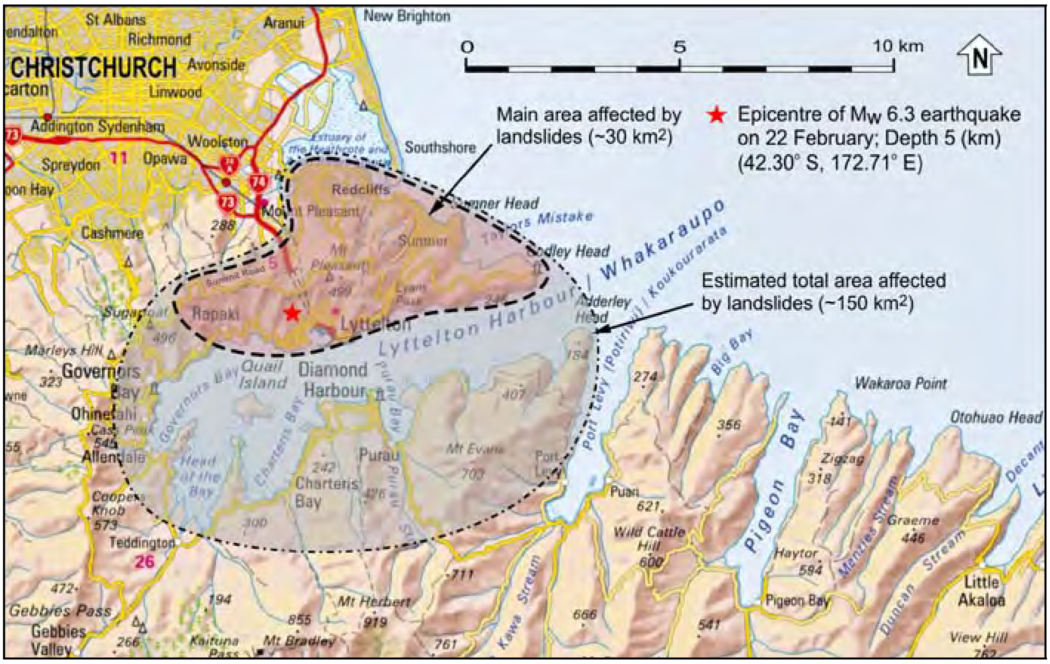

Figure 3. Areas affected by landslides triggered by the 22 February 2011 earthquake.

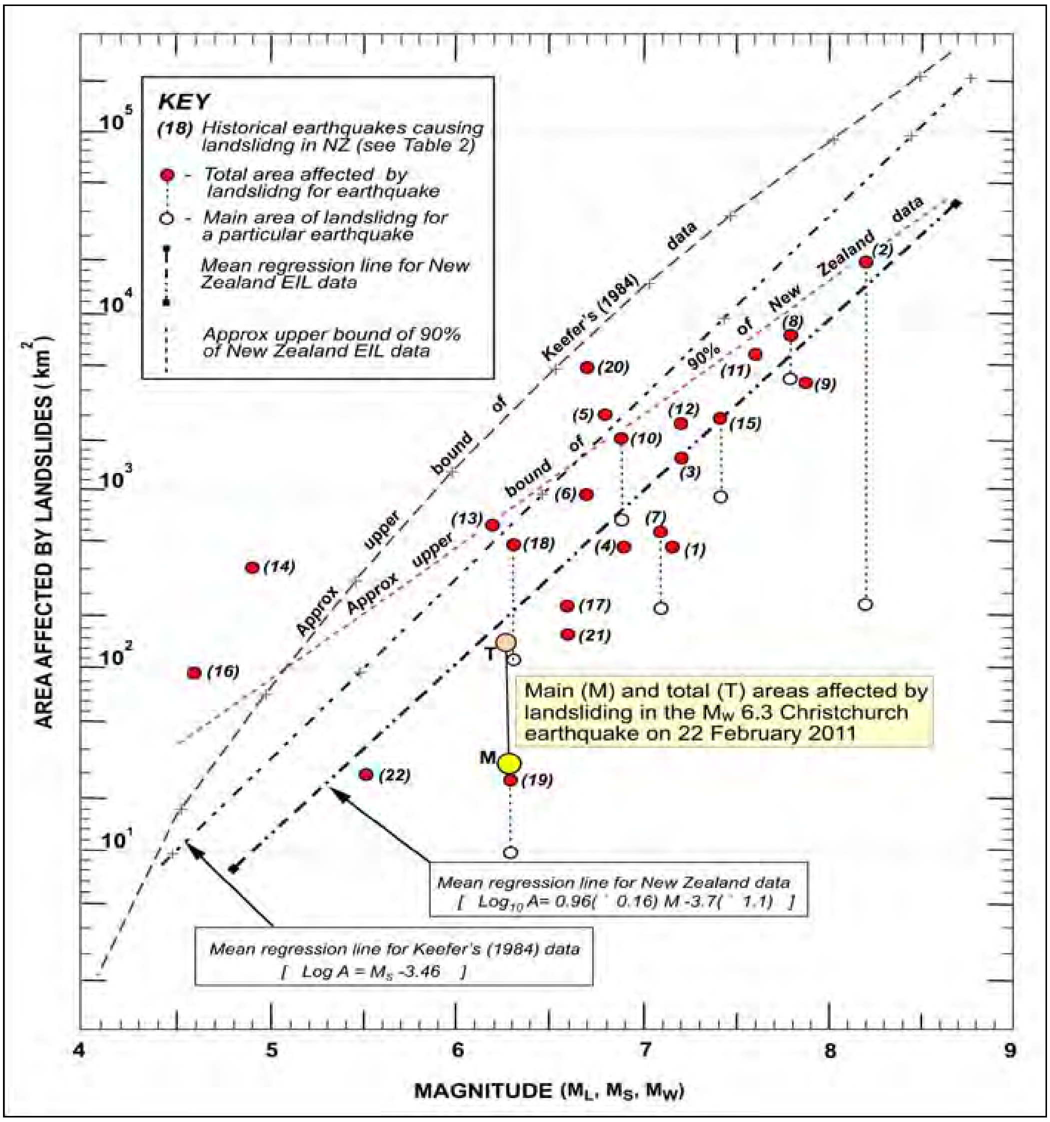

Figure 4. Graph showing the main area (~30 km^2) and estimated total area (~150 km^2) affected by landsliding during the M_w 6.3 Christchurch earthquake of 22 February 211 compared to areas affected by landslides during earthquakes in New Zealand *(as determined by Hancox et al. 2002).*

Photo 1. Small rock and debris falls on ~100 m high sea cliff at Godley Head *(GNS Photo-GTH_5622)*.

Photo 2. Small rock and debris falls on ~100 m high cliff below Searidge Lane at Sumner Head, Scarborough *(GNS Photo-GTH_5654).*

Photo 3. Tension cracks *(C)* along the cliff edge close to houses on Searidge Lane at Sumner Head *(GNS Photo-GTH_5661)*.

Photo 4. Rock and debris falls on ~50 m high cliff behind houses at the north end of Wakefield Ave, Sumner. This is an old quarry site *(GNS Photo-GTH_5699)*.

Photo 5. Small rock falls and boulders on gardens close to houses between Arnold and Colenso streets, Wakefield Ave, Sumner *(GNS Photo-GTH_5700)*.

Photo 6. Large rock fall behind the RSA Building at 34 in Wakefield Ave, Sumner (rock fall fatality reported at building site left) *(GNS Photo-GTH_5708).*

Photo 7. Rock falls on cliff face behind RSA and Backpakers buildings at corner of Wakefield Ave (left) and Nayland Street (right), Sumner *(GNS Photo-GTH_5712)*.

Photo 8. Rock falls at RSA and Marine Backpackers site, Sumner *(GNS Photo-GTH_5714)*. Note badly damaged houses top left (*see Photo 8a- same location as Photo 8)*.

Photo 8a. Houses on Richmond Hill Road badly damaged by strong shaking at top of 50 m high cliff above RSA building at Sumner *(GNS Photo-GTH_5723).*

Photo 9. Fall of large boulders at the back of damaged houses at 11 (left) and 9 (centre) Richmond Hill Rd, Sumner *(GNS Photo-GTH_5727).*

Photo 10. Fall of large boulders at the back of damaged houses at 11 (bottom) and 9 (centre) Richmond Hill Rd, Sumner *(GNS Photo-GTH_5736)*.

Photo 11. Rock falls on cliff face below Kinsey Tce on to 'Peacocks Gallop' reserve along Main Road between Sumner and Moncks Bay *(GNS Photo-GTH_5745).*

Photo 12. Rock falls on cliff (a former quarry site) below Kinsey Terrace on the Main Road between Sumner and Moncks Bay (right). *(GTH_5749).*

Photo 13. Rock falls below Kinsey Tce on to the Main Rd at the Moncks Bay–Shag Rock headland at Sumner *(GNS Photo-GTH_5753).*

Photo 13a. The earthquake also shattered the well-known Shag Rock at Sumner *(GNS Photo-GTH_5836, after 5837; before by Webphotos- location same as 13).*

Photo 14. Cliff top cracking *(C)* along the cliff edge and affecting houses *(C1)* in Kinsey Terrace on Moncks Bay headland *(GNS Photo-GTH_5771).*

Photo 15. Rock falls and cracking (C) in Kinsey Tce, Moncks Bay *(GNS Photo-GTH_5775)*.

Photo 16. Large and damaging rock falls behind Redcliffs School (right) and houses in Raekura Place (left) in Redcliffs (also an old quarry site). *(GNS Photo-GTH_5785)*.

Photo 17. House destroyed by rock fall in Raekura Place at Redcliffs. The houses left (#54) and centre (#44) are reported fatality sites, (*GNS Photo-GTH_5787)*.

Photo 18. Large rock and debris falls on the ~60 m high cliff face behind Redcliffs School *(GNS Photo-GTH_5801)*.

Photo 19. Large rock falls on the cliff behind Redcliffs School and Moa Cave Guest House, Redcliffs *(GNS Photo-GTH_5792).*

Photo 20. Rock falls on cliff face into Moa Cave Guest House grounds, Redcliffs *(GNS Photo-GTH_5796).*

Photo 21. Rock falls on cliff behind Redcliffs School below Glendevere Terrace at Redcliffs *(GNS Photo-GTH_5814)*.

Photo 22. Cliff-top cracks *(C)* in roads and affecting properties in Glendevere Terrace, Redcliffs *(GNS Photo-GTH_5816)*.

Photo 23. Cliff-top cracking *(C)* in Glendevere Terrace, Redcliffs *(GNS Photo-GTH_5819)*.

Photo 24. Large rock fall at Moa Cave Guest House, Main Road, Redcliffs *(GNS Photo-GTH_5822).*

Photo 25. Rock fall on to house at 116A Main Road, Redcliffs *(GNS Photo-GTH_5823)*.

Photo 26. House at 241 Governors Bay Road, Rapaki, hit by a large (~3 m long) boulder 3 km west of Lyttleton *(GNS Photo-GTH_5842).*

Photo 27. House hit by large boulder *(B)* at Rapaki *(GNS Photo-GTH_5846)*.

Photo 28. Source area *(S on 405 m peak)* and travel path of the boulder *(B)* that hit the house 241 Governors Bay Road *(H)* at Rapaki *(GNS Photo-GTH_5853).*

Photo 29. Rock fall on slope and walking track below Gondola Building (possible fatality site) *(GNS Photo-GTH_5933).*

Photo 30. Numerous small rock falls from lava bluffs on to Summit Road near the Gondola Building *(GNS Photo-GTH_5993).*

Photo 31. More rock falls on to Summit Road *(GNS Photo-GTH_5998).*

Photo 32. Rock falls from Castle Rock on to old talus slope. Most are from the 4 Sep 2010 earthquake, with some from the 22 February event *(GNS Photo-GTH_6017).*

Photo 33. Large boulders from rock falls on Castle Rock (mainly during the 4 September earthquake) near west Tunnel Portal *(GNS Photo-GTH_6084).*