9. ROCKFALL AND LANDSLIDES

Rockfalls, block failures, and other forms of landslides were widespread in the near-fault region around the Port Hills south of the City of Christchurch. These slope failures resulted in five deaths and damaged or destroyed many roads, tracks, and structures. Almost every cliff face in the Port Hills generated rockfall, while over-steepened road cuts and quarry walls often failed by block collapse or by generating large volumes of rockfall. Rockfalls were the most widespread and devastating slope failures, causing the five deaths and damage to structures. Deep-seated landslides were found only at a couple of locations, most of which were at the top of coastal headlands. Numerous failures occurred in retaining walls and fill slopes, resulting in damage to roads, property, and commercial and residential structures. A map prepared by GNS Science showing the location of various types of slope failures observed in the Port Hills is presented as Figure 9-1.

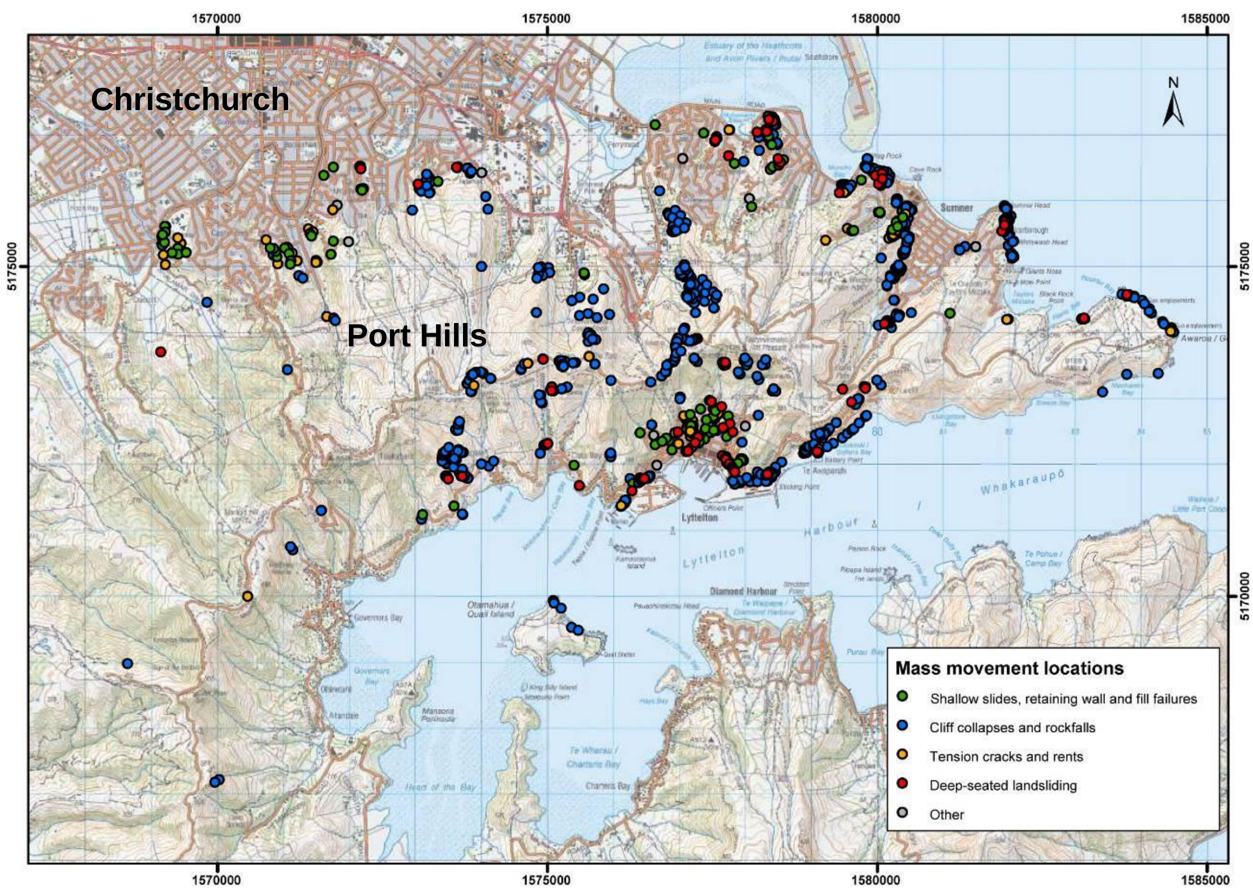

Figure 9-1. Map showing the distribution of the different types of mass movements in the Port Hills (Dellow et al., 2011).

The University of Canterbury, GNS Science, and Environment Canterbury (ECan) conducted rapid assessments of the locations of rockfalls and other landslides to identify areas where there damage had occurred as well as to identify areas/homes at risk from further slope failures. Because of most of the Port Hills residential communities were impacted by rockfall and landslides, most areas were investigated both by road and on foot to document potential for further mass-wasting during aftershocks and precipitation events. GEER team members visited selected areas to further document the nature of slope failures, the type and extent of damage to infrastructure and buildings, and in several cases, to document the performance of slope stability and rockfall protection measures. Field observations were supplemented by visual interpretation of aerial imagery using Google Earth with pre- and post-earthquake imagery.

Observations from Field Reconnaissance

Field reconnaissance was undertaken from 22 February 2011, immediately after the earthquake, by G. De Pascale and by other members of the GEER team from 2 March through 5 March. The reconnaissance observations in this section focus on the Port Hills, from Mt Cavendish east towards Godley Head and all slopes radiating from the top of Summit Road above the communities of Heathcote, Lyttelton, Mt. Pleasant, Redcliffs, Clifton, and Sumner. The locations of these suburbs and towns around the Port Hills are shown in two oblique views on Figure 9-2, one looking south over southern suburbs of Christchurch, and one looking north across the communities of the southern Port Hills.

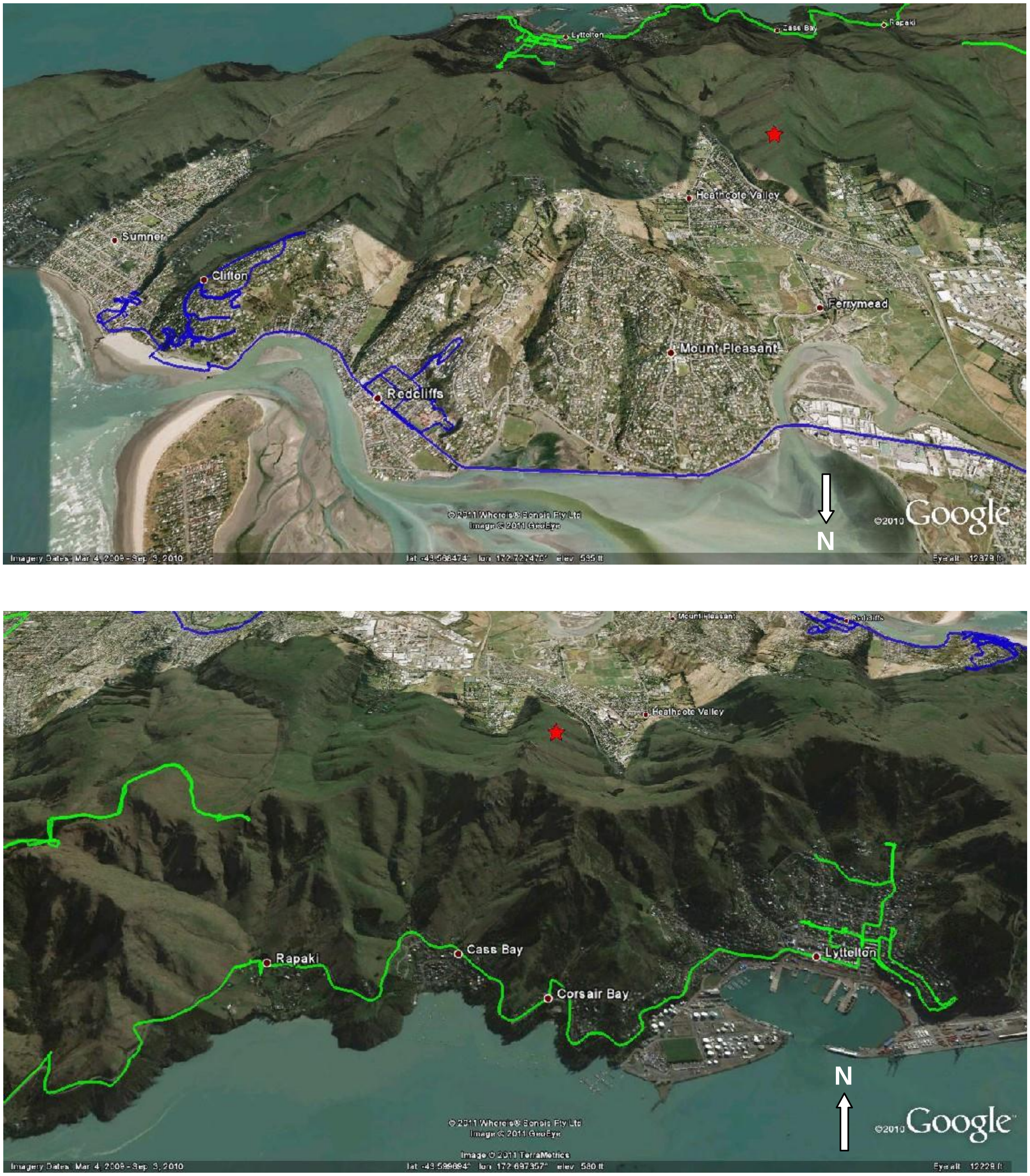

Figure 9-2. Oblique aerial views from Google Earth imagery. Red star is epicenter of 22 February 2011 earthquake (U.S. Geological Survey). Top – View from above New Brighton (eastern Christchurch) directly south across Port Hills, Blue line is GPS track from GEER team reconnaissance on 5 March 2011. Bottom – View from above Diamond Harbor and Quail Island

directly north across Port Hills. Green line is GPS track from GEER team reconnaissance on 4 March 2011.

Numerous rockfall, block failures, or slumps were observed in over-steepened road cuts and quarry walls composed of weathered volcanic rocks and overlying loess, even where retaining walls were present, as shown on Figures 9-3 and 9-4 from the upland suburb of Mt Pleasant. These over-steepened cut slopes had approximate inclinations of ¼H:1V or steeper; and were from 1 to 10 meters high for the road cuts in loess and up to 100 m high for quarry faces in the volcanic rocks. For the loess slopes, the failed material formed a debris apron covering half or more of the road.

Figure 9-3. Failed retaining wall and slumping in loess, blocking a road on lower Mt Pleasant (-43.55617°, 172.7156°).

Figure 9-4. Blocks of loess that fell from a 10 m road cut on Mt Pleasant (-43.5565°, 172.7147°).

Both natural and modified (quarry) volcanic rock faces were sources of both rockfall and block collapse, forming large talus slopes at the base of cliffs, or rockfall run out on some slopes. The volcanic rocks exposed across the northern part of the Banks Peninsula are part of the Lyttelton Volcanic Group, and include dominantly basaltic to trachytic lava flows interbedded with breccia and tuff, and lava domes (Forsyth et al., 2008). Most of the cliffs along Main Road and Wakefield Avenue from Mt. Pleasant to Sumner, which have from about 20 to 100 m of relief, experienced large-scale rockfall and block collapse as a result of strong ground shaking during the February earthquake. More than twenty residential and commercial buildings downslope of the cliffs in Redcliffs and Sumner were destroyed by rockfall debris that formed an apron of talus along the base of the cliffs (Figures 9-5, 9-6, 9-7, and 9-8). Boulders were sub-angular to angular, and ranged from cobble-sized to house-sized (up to 10 m in diameter). Individual boulders often rolled or tumbled 10's of meters beyond the base of the talus wedge and in places obstructed the road. In both Redcliffs and Sumner, several people were killed in their homes or place of work by rockfall. Several types of rockfall protection measures were present at the base of the quarry wall in the Redcliffs. These included a gabion, rockfall fences, and a rock berm. The gabion performed well in stopping the block collapse of the cliff from impacting the house below the gabion (Figures 9-9 and 9-10). Two rockfall fences adjacent to the gabion were less successful, as both were filled and overtopped by the large volume of the block failure. A rock berm was constructed along the schoolyard border at the base of the quarry wall, possibly using debris from more limited rockfall that may have been generated by the 4 September 2010

Darfield earthquake (the berm is not present on the 2009 pre-earthquake imagery; Figure 9-7 top). This berm was successful in protecting the schoolyard, as no rocks were observed in the area east of the fence beyond the rock berm (Figure 9-11).

Figure 9-5. The Sumner RSA building was destroyed by a massive block that fell from the cliff-face (-43.5700°, 172.7586°). Top – Street view. Bottom – Aerial view (New Zealand Land Information Post-Earthquake Imagery)

Figure 9-6. Photo showing cliff face in the suburb of Redcliffs, with fresh talus at the base and Christchurch CBD and the Southern Alps in the background (-43.5596°, 172.7374°).

Figure 9-7. Pre-Earthquake (4 March 2009; top) and post-earthquake (23 February 2011; bottom) Google Earth GeoEye imagery oblique views of cliff walls in Redcliffs. Red line shows approximate pre-earthquake top of cliff. Location of photographs on Figures 9-8 to 9-11 shown on lower image.

Figure 9-8. Home at the base of cliff in Redcliffs with wedge of talus boulders inundating the structure and roundabout, taken 22 Feb 2011. (-43.5610°, 172.7341°).

Figure 9-9. Photo showing the gabion behind house at base of cliff in the suburb of Redcliffs. No damage to house from rockfalls was observed (-43.56074°, 172.73379°).

Figure 9-10. Photo showing slight movement of upper part of gabion behind house at base of cliff in the suburb of Redcliffs. Gabion performed well in stopping rockfall and talus from impacting house (-43.56067°, 172.73367°).

Figure 9-11. Photo showing rock berm constructed to protect schoolyard at base of cliff in Redcliffs. The berm apparently performed well in stopping rockfall and talus as the fence bounding the school field (note wood posts at center left) was not significantly damaged and no rocks were observed on the field (-43.55972°, 172.73298°).

Evan’s Pass road, the only direct transportation route and thus a lifeline between Sumner and the Port of Lyttelton, was closed due to rockfall blocking the road and trapping a transport truck. Rockfall and rock topples occurred on many of the over-steepened road cuts and from natural cliffs above the road alignment (Figure 9-12). These failures impeded delivery of relief supplies and critical transport between the port and the southern suburbs. In some locations, rockfalls occurred along bedding planes (e.g. Windy Point), however most rockfall occurred from cliffs composed of jointed columnar basalt and trachyte (Figure 9-13).

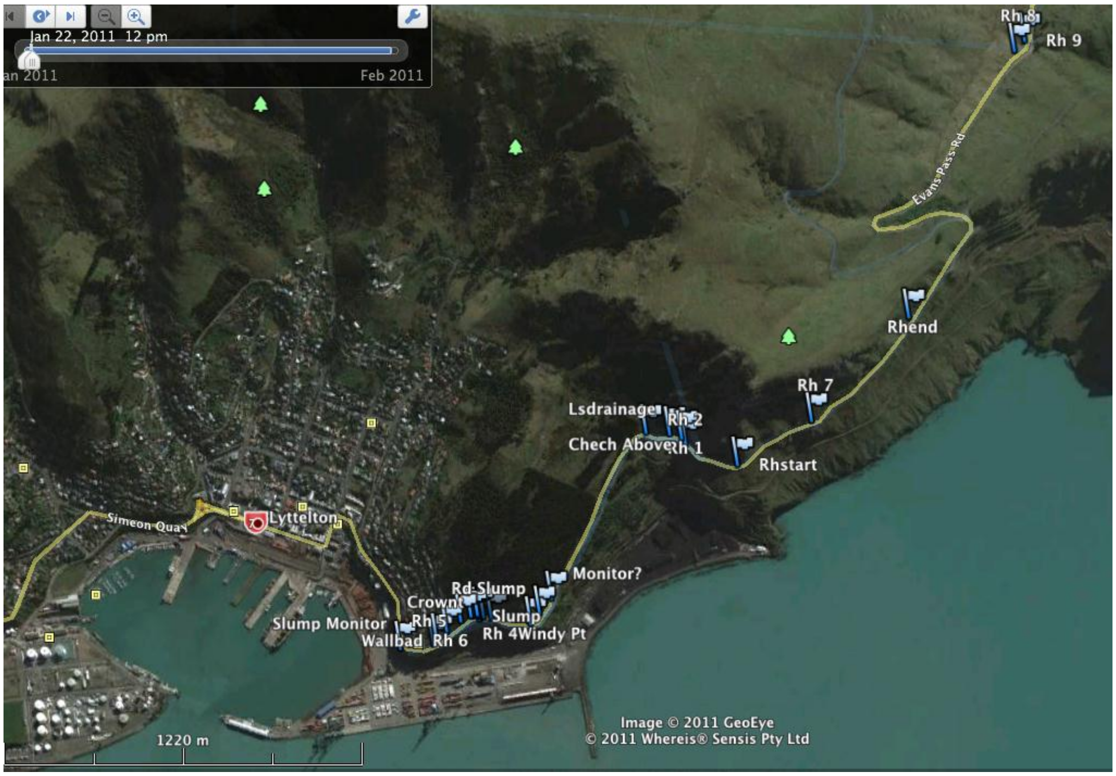

Figure 9-12. Evan’s Pass Rd to Lyttelton and locations of Rockfall and slumping from reconnaissance on 25 Feb 2011.

Figure 9-13. Rockfall along Evan's Pass Road, with columnar jointed source areas above road in background. (-43.6007°, 172.7354°).

Natural exposures in the Lyttelton Volcanic Group form many steep slopes, and in some places near-vertical cliffs across the Port Hills. Rockfalls, topples, and collapses occurred in many areas, and resulted in fatalities and injuries to people and damage to buildings located along or near the base of the slopes. Individual boulder rockfall was widespread throughout the Port Hills in southern Christchurch, and many homes and commercial sites were hit by boulders that traveled long distances from the source area cliffs - in many cases having runouts greater than 500 m. Because many cliffs occur 300 to 500 m directly above some communities (e.g. Lyttelton, Cass Bay, Rapaki, Morgan's Valley, etc.) with steep slopes extending from the cliffs down to near sea level, strong ground shaking and resulting rockfall generated boulders that rolled and bounded downslope into these and other communities at the base of the Port Hills.

One location that was visited to conduct detailed mapping was Morgan's Valley above the Heathcote Valley, which had the highest recorded PGA during the 22 February earthquake. Detailed ground mapping was undertaken in Morgan's Valley to document rockfall occurrence and the potential for additional rockfall, as many of the homes remained inhabited post-earthquake. The rockfalls (individual boulders) caused by the 22 February event were located using GPS, and the mapping showed that at least six houses were hit by rockfall, with a number of additional near-misses (Figures 9-14, 9-15, 9-16, 9-17, and 9-18).

Figure 9-14. Boulder locations mapped 22-25 February 2011 in Morgan's Valley. Red shaded area was identified as the potential rockfall hazard zone.

Figure 9-15. Boulder imbedded in house at the top of Morgan's Valley, affectionately known as "Rocky" was sold for charity on the internet for $60,000 NZ. (-43.58052°, 172.71669°).

Figure 9-16. House with hole on left side from rockfall, note cliff source areas above with fresh talus. (-43.58126°, 172.71672°).

Figure 9-17. Boulder perched on driveway with source area above ~ 400 m away (-43.58202°, 172.7177°).

Figure 9-18. Earthquake induced rockfall with geologist for scale. Boulder along left side of photo is lichen-covered in place, and therefore pre-dates the Feb 22, 2011 event (-43.58187°, 172.71632°).

Rockfall in Rapaki from the February earthquake resulted in severe damage to several homes. A massive boulder passed through one house, apparently while airborne as an impact mark is present on the lawn above the house, and the floor in the impact area reportedly was not badly damaged (Figures 9-19, 9-20, and 9-21). Additional rockfall was observed on slopes above Lyttelton.

Figure 9-19. House in Rapaki damaged by rockfall. Rockfall originated from cliffs at an elevation approximately 250 to 300 m above house (-43.60475°, 172.67920°).

Figure 9-20. House in Rapaki damaged by rockfall. Note impact mark on lawn at bottom of photograph. Boulder may have fractured into two or more blocks as there appear to be two impact areas on the up-slope facing wall of the house (-43.6044°, 172.6780°).

Figure 9-21. Earthquake induced rockfall in Rapaki with geologists for scale. Boulder passed through house at top center of photograph (-43.60478°, 172.67931°).

Numerous rock retaining walls in Lyttelton failed as a result of the February earthquake. These walls apparently were constructed of random angular blocks or rectangular blocks, with no reinforcement or mortar (Figure 9-22).

Figure 9-22. Rockwall collapse in Lyttelton. Top: Angular random size block wall (-43.59949°, 172.71717°). Bottom: Rectangular block wall (-43.60069°, 172.71903°).

Several large deep-seated landslides were mobilized during the 22 February earthquake. Fortunately, the movement of these slides was relatively small, perhaps due to the relatively short duration of strong ground shaking. Generally these landslides were manifested as sets of open crown fractures or tension cracks that extended up to 500 m along the surface with vertical or steeply dipping scarps up to approximately one meter height. The fractures or cracks were tight to open, up to 50 cm wide and often ranged from 35 cm to several meters deep. The most impressive of these landslides was identified on Clifton Terrace above Sumner where cracks extended for hundreds of meters across many properties and through several houses (Figures 9-23 and 9-24). The GNS Science installed several continuous GPS monitoring stations to monitor potential post-earthquake movement (Figure 9-25). Similar crown fractures or tension cracks were found on Scarborough Terrace, with fractures/cracks extending through several homes above Taylor's Mistake. A number of crown cracks were also found at Godley Head (Figure 9-26).

Figure 9-23. Landslide headscarp on Clifton Terrace with monitoring stakes. (-43.56543°, 172.75204°).

Figure 9-24. Landslide headscarp extending beneath house on Clifton Terrace. House was thrown off foundation, and foundation was cracked in several places along headscarp (-43.56586°, 172.75256°).

Figure 9-25. Continuous GPS monitoring station installed on Clifton Terrace by GNS to monitor post-earthquake slope movement (-43.56586°, 172.75272°).

Figure 9-26. Location of deep-seated landslides along headlands in the Eastern Port Hills.

Reference

Dellow, G.D., Massey, C.I., Davies, T.R.H., Read, S.A.L., Bruce, Z.R.V, VanDissen, R., Barrell, D., Jongens, R., Heron, D., Glassey, P., Hancox, G.T., Perrin, N., McSaveney, M.J., Archibald, G.C., Palmer, N. McSaveney, E.R., Lukovic, B., Andres, N.M., Hasse, M., Beavan, J., Edwards, S., and Thomas, J. (2011). Rockfalls and landslides triggered by the February 2011 Christchurch (NZ) earthquake: the GeoNet response: EGU General Assembly, Vienna, EGU2011-14230, special session US4 The 22 February 2011 Christchurch Earthquake, 2011 (www.gns.cri.nz).