

Geosciences 2013

Annual Conference of the Geoscience Society of New Zealand.
Christchurch.

Field Trip 2

Sunday 24th November 2013

Earthquake Engineering Geology: Port Hills and Christchurch City.

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Cover photo: Shag Rock at the entrance to the Avon-Heathcote Estuary, modified in the Canterbury Earthquake Sequence, and now locally referred to as Shag Pile.

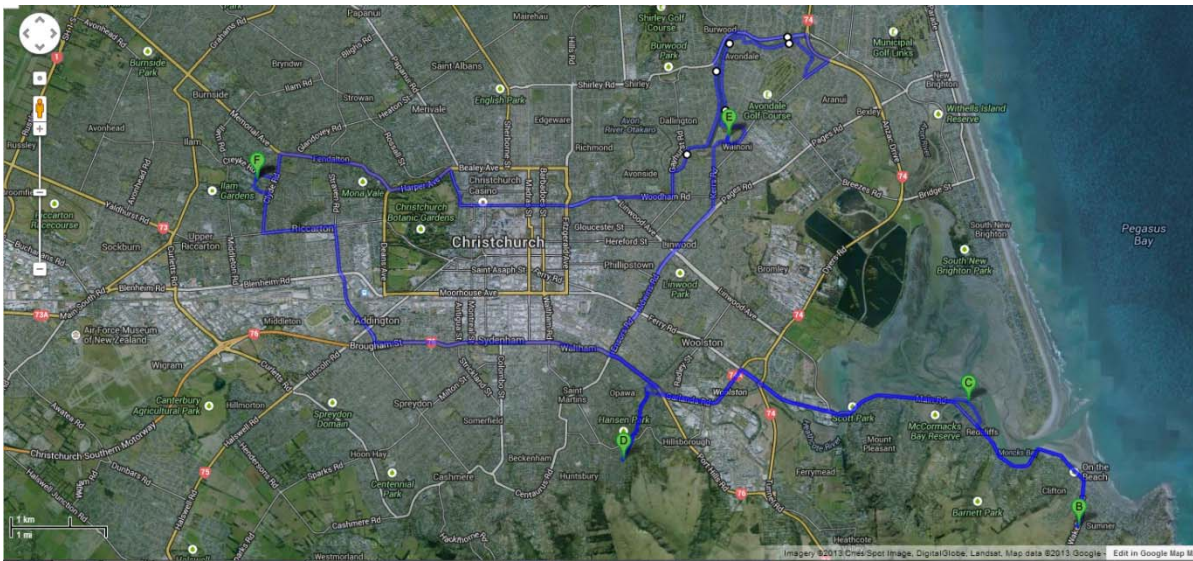
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Health and Safety:

Most of the field trip stops will be off-street in local parks, however please take care if crossing roads. All roads are public, with some being busy and congested due to remediation work in the area. High visibility vests will be provided, so please wear these whenever not on the bus. Sturdy footwear is recommended, however we will not venture far from the coach at most locations.



Route:

Leave 11.00 am and travel from University of Canterbury to Sumner (Wakefield Avenue). Sumner to Redcliffs, Huntsbury Hill (Vernon Terrace), via Opawa to Porritt Park, and Dallington. Return to University of Canterbury by 5.30 pm.

Background

New Zealand is located at a plate boundary between the Pacific and Australian plates (Figure 1). However, all of the relative motions between the Australian and Pacific plates are accommodated on many faults across a much wider zone. At 4:35am (NZ Standard Time) on September 4th, 2010 the rupture of the previously unrecognized Greendale fault beneath the Canterbury Plains of New Zealand's South Island produced the M_w 7.1 'Darfield' earthquake that caused widespread damage throughout the region and represents the start of a period of heightened seismicity in the Canterbury Regions that is expected to continue for several decades. Damage to buildings and infrastructure from this earthquake was concentrated in the Darfield area (near the epicentre of the earthquake) and liquefaction occurred in the Eastern Suburbs of Christchurch, and at Kaiapoi. Minor damage occurred in Christchurch, generally in the form of collapsed chimney stacks and older unsupported walls. Rockfall associated with the Darfield earthquake was generally limited, with only two boulders observed to be released onto a driveway.

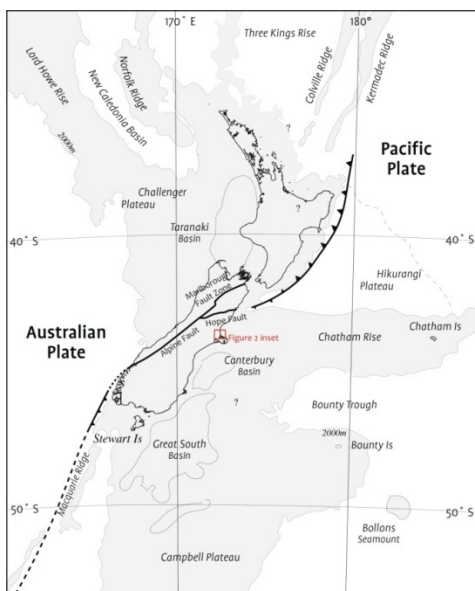


Figure 1: Geological Setting Maps

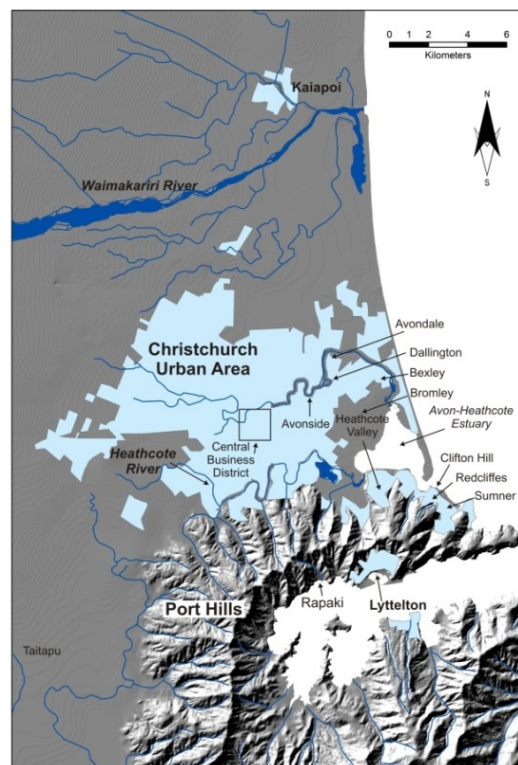


Figure 2 Location map

At 12.51pm (NZ Standard Time) on 22 February 2011, a M_w 6.3 earthquake occurred ~10 km south-east of the centre of Christchurch Central Business District, CBD, at a shallow depth of ~5 km. The Christchurch Earthquake caused widespread damage throughout Christchurch, in the form of shaking and liquefaction damage, as well as rockfall and cliff collapse on the Port Hills, Banks Peninsula (Figure 2). There were 181 fatalities, the majority of whom were killed in building failures; two fatalities were caused by rockfall and three from cliff collapse. The consequences of the cliff collapse that occurred during the Canterbury Earthquake sequence has affected residents both at the top and the base of the cliff.

On 13 June 2011 a significant M_w 6.1 aftershock struck Christchurch in an extension to the continued expanding trend of aftershock just east of Christchurch. This earthquake resulted in strong shaking throughout the city and caused many areas to re-liquefy, and further rockfall and cliff collapse combining to cause additional lifeline disruption and damage.

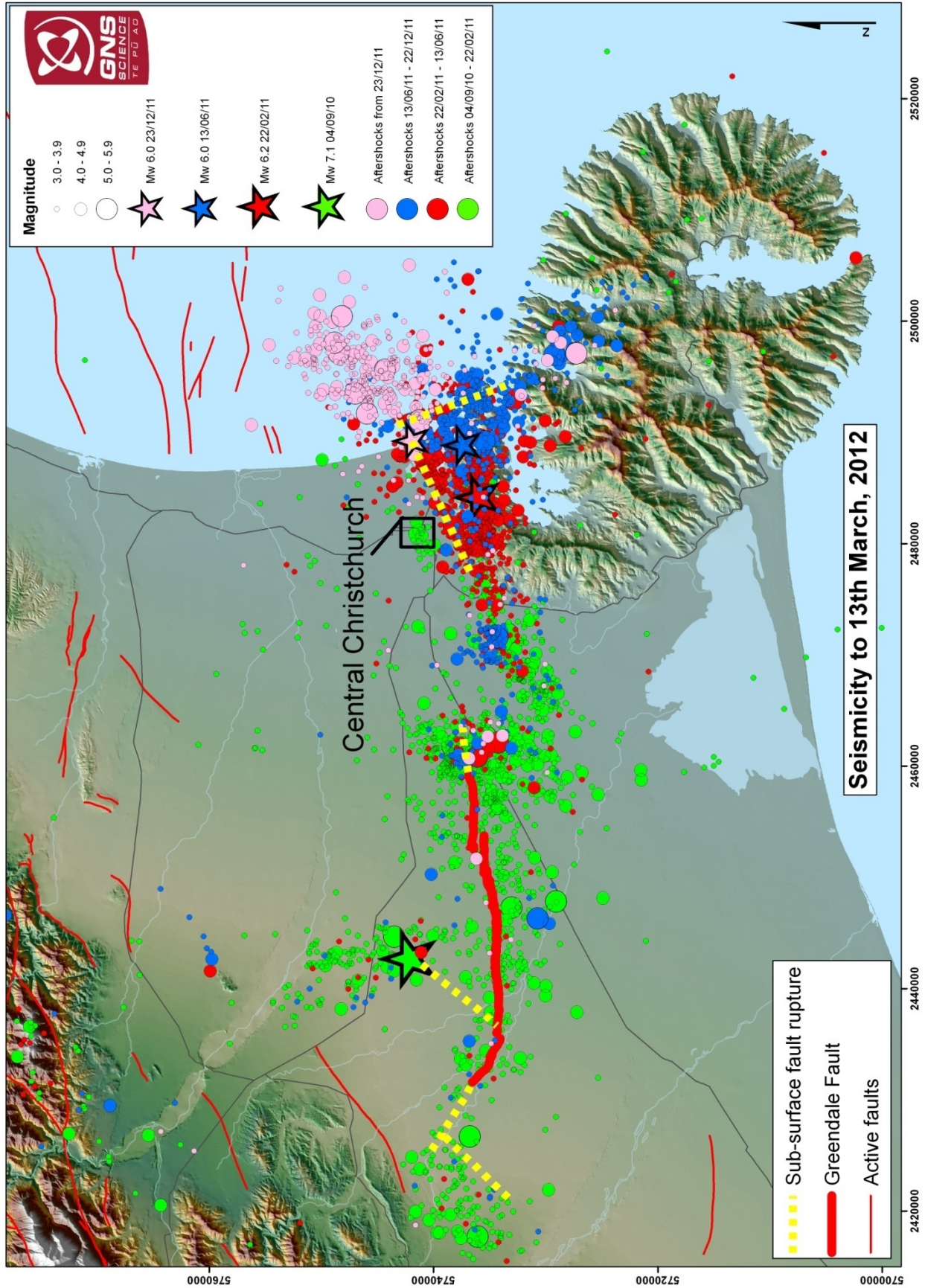


Figure 3 Map of seismicity, GNS

Stop 1 Wakefield Avenue (Drive Past)

Wakefield Avenue is the site of partial cliff collapse during the 22 February 2011 earthquake, especially at the RSA (northern) end where sadly one death occurred (a worker on the site). Temporary protection measures involved the construction of a double-container wall adjacent to Wakefield Avenue, reducing the road width. Other sites were effectively sterilised in terms of access, such as the Anglican Church and the Bowling Club, as the risk of further cliff collapse (eg during the 13 June 2011 earthquake) was too great. These sites have effectively been abandoned, and it is of note that one of the field trip leaders (David Bell) was working on protection measures for a column of rock that could potentially damage the Anglican Church at the time. The column did not collapse, and the church itself has not been inundated by rock debris although boulders up to 100 tonnes in mass had previously been released from the cliff face and were present about 20m back from the church. Drilling by GNS on Richmond Hill above Wakefield Avenue has provided some suggestion of movement on red ash/tuffaceous units, but a major dike along the front of the cliff is also thought to be a geological control on partial cliff collapse due to the high ground accelerations ($>1.0g$) experienced along the cliff face.

Stop 2 Clifton Hill/ Shag "Pile"



Figure 4 Shag Rock before (wikipedia.org)

and after (cbc.ca).

Stop 2 will involve a stroll on the beach at the entrance to the Avon-Heathcote estuary, subject to the tide having gone out far enough. The purpose is to view the face of Clifton Hill, and the area known as Peacock's Gallop because he had to gallop his horses to avoid rockfalls from the cliff. Prior to the 22 February 2011 earthquake wave-cut stacks in bedrock were evident, and the cliff face had been trimmed by wave action when sea level reached its present elevation some 6,500 years ago (Brown and Weeber, 1992). The earthquake of 22 February 2011 caused cliff retreat by up to 15m locally, and a similar amount of localised retreat followed on 13 June 2011. Both events generated peak ground accelerations in excess of 1.0g (vertical and horizontal), with cliff collapse in the sequence of some seven lava flows which were a standard viewing stop for more elementary field trips.

Multi-million dollar houses near the cliff edge have been vacated, and some are now at the bottom of the cliff. This land east of Kinsey Terrace has been largely red-zoned for obvious reasons, and the fracturing in bedrock extends back metres behind the present cliff face. The construction of a double-container wall has provided adequate protection for Main Road, but the long-term prognosis means that some realignment or more permanent protection may be required. Evans Pass through to Lyttelton remains closed, and there is no real alternative access to Sumner except via the Summit Road and Mt Pleasant Road. Land instability in colluvial materials affecting Clifton Terrace further exacerbates the situation for local residents.

Stop 3 Redcliffs Park

The area adjacent to Redcliffs School is a former shore platform embayment that developed during the postglacial period of marine transgression that was followed by shoreline progradation and alluvial sedimentation sourced primarily from the Waimakariri River. Today Redcliffs is a residential area with single and double storey housing, a primary school and public roads set close to the cliff area. The flat land at the base of the cliff comprises marine sands and silts and lies approximately 5-10 m above mean sea level (Brehaut, 2012)

Cliff collapse occurred at the Redcliffs site during the 22 February 2011 earthquake, forming a large debris slope at the base of the cliff. Cliff collapse occurred again during the M_w 6.3 13 June 2011 aftershock, causing further retreat of the top of the cliff. Rock runout exceeded the pre-existing talus in places. Cumulative cliff retreat of the order of 10-15m has occurred in both earthquake events (February and June 2011). Due to cliff retreat a number of houses at the top of the cliff have been damaged and subsequently abandoned. Similarly, within the Redcliff area, six buildings have been impacted by rockfall, of which four have been removed or abandoned due to irreparable damage.

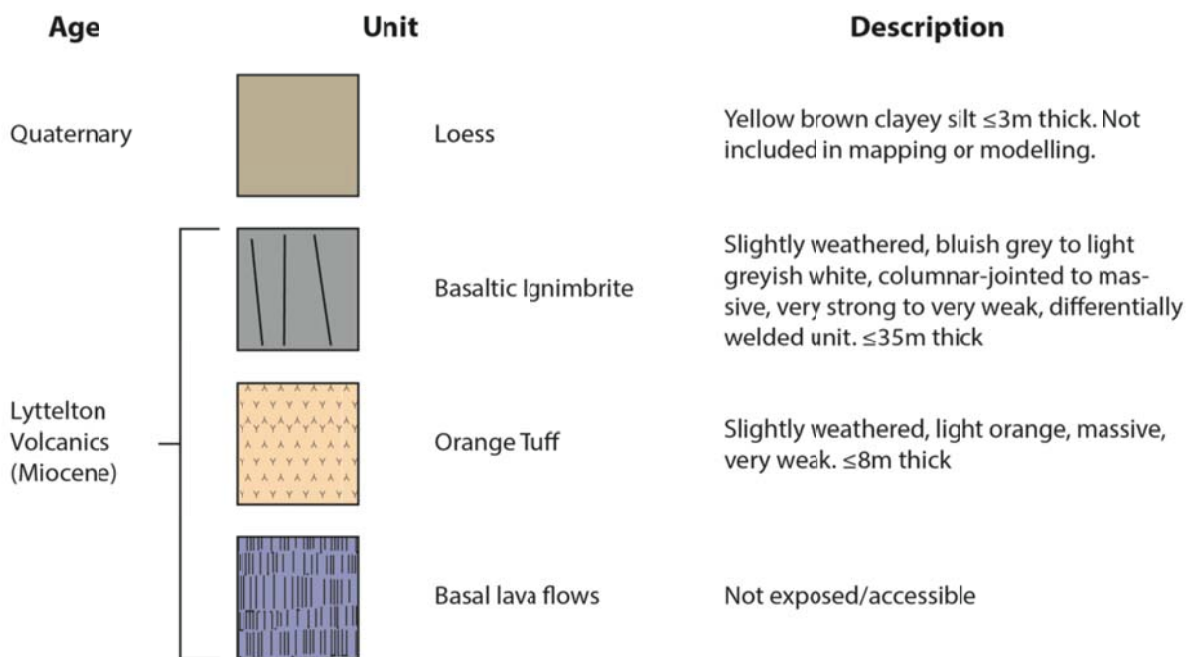


Figure 5 Simplified Redcliffs Stratigraphy

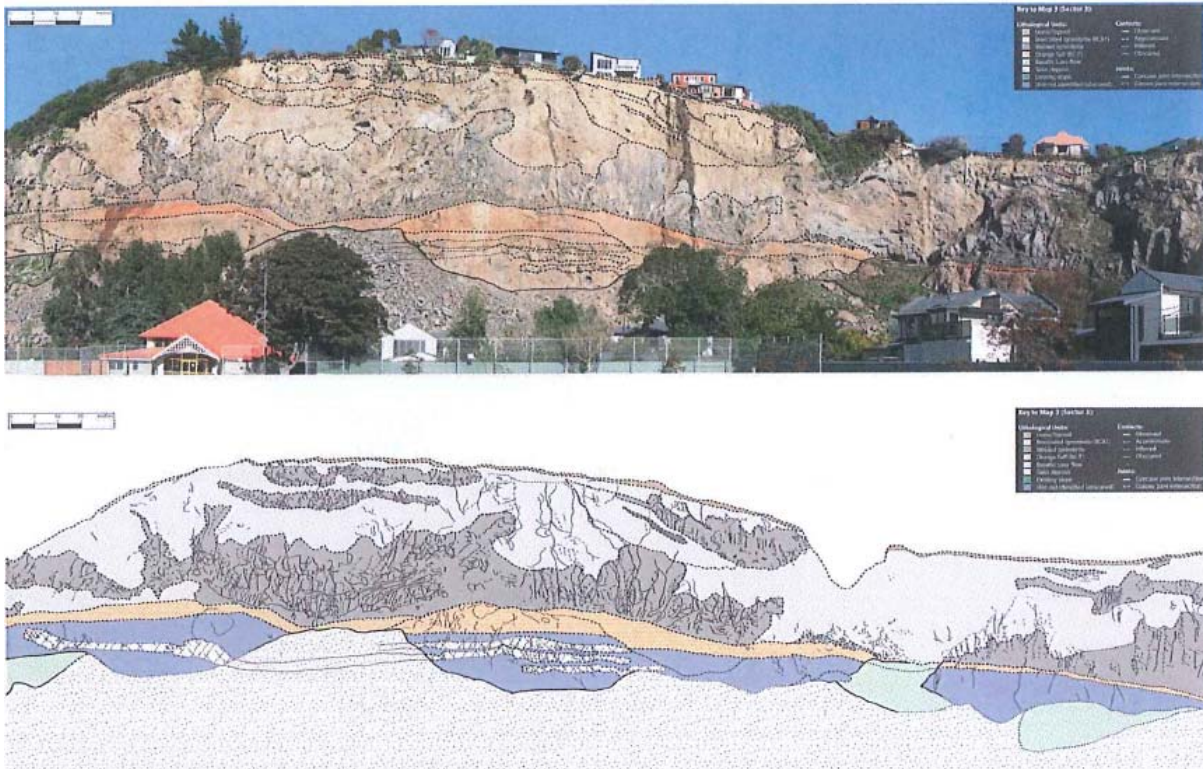


Figure 6 Sector 3 face log

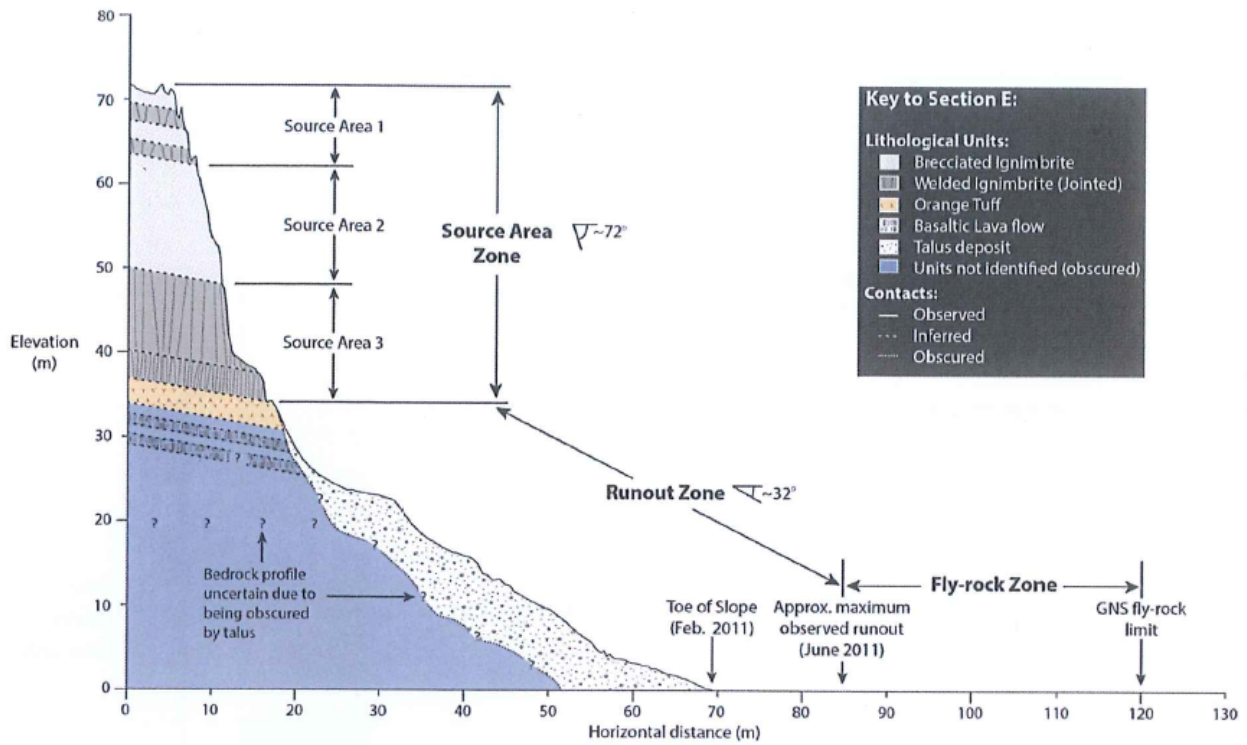


Figure 7 Cross section (of section E) – School Hall



Figure 8 Photo showing runout adjacent to Section E

Landslide Hazards

Rockfall

The southern and south-eastern suburbs of Christchurch are constructed on the Port Hills, which were constructed 9.6-12 million years ago by the now extinct Lyttelton volcano. The Port Hills consist mainly of jointed basaltic lava flows, commonly interbedded with layers of clay-rich tuffaceous and epiclastic deposits. On the eastern seaward side the lava flows have been eroded by coastal processes during the last glaciation (ending ~6,000 years ago), forming steep cliffs, a shore platform beneath and a series of small harbours. Prior to the 22 February 2011 earthquake rock falls, boulder roll and loess soil failure had been the only significant slope hazard considered for the Port Hills.

Rockfalls mostly occurred from the jointed lava flows, leading to tens of houses being impacted by falling rock in Redcliffs, Heathcote Valley, Lyttelton, Rapaki and Sumner. The mitigation measures in place (fences, benches and trees) were overwhelmed by the large number and volume of rocks, which came down off the hills. During the 22 February and 13 June earthquakes, large-scale cliff collapses occurred in Redcliffs and Sumner (south-east Christchurch suburbs). Up to 15 m of cliff failed along sub-vertical cooling fractures and through intact rock during each shaking event due to very high vertical and horizontal accelerations ($>1.0g$). This led to hundreds of houses being severely damaged, requiring evacuation, and ~100 houses unlikely to be reoccupied both at the cliff top and base. Power, water and sewage services were also severely damaged in the hill suburbs. Clifton Hill collapses threatened the seaward road linking Redcliffs and Sumner to Christchurch city, requiring the use of ballasted shipping containers to be used as a temporary catch fence (Figure 9).



Figure 9 Cliff collapse at Clifton Hill following the 22 February and 13 June 2011 earthquakes - flown 14 June 2011. Note the partially collapsed house and use of ballasted shipping containers as temporary catch fences (Photo credit: Marlène Villeneuve/David Bell).

Since September 4th 2011 GNS Science and geotechnical teams have been mitigating rock fall hazards. To gain a further understanding of rock fall trajectories, including runout distances, zone of runout and influence of variables (i.e. slope, source, rock/block size and angularity), GNS Science has predicted a zone / window of potential runout, bordered at the source area by a 30° runout constraint (see figures 10 & 11).

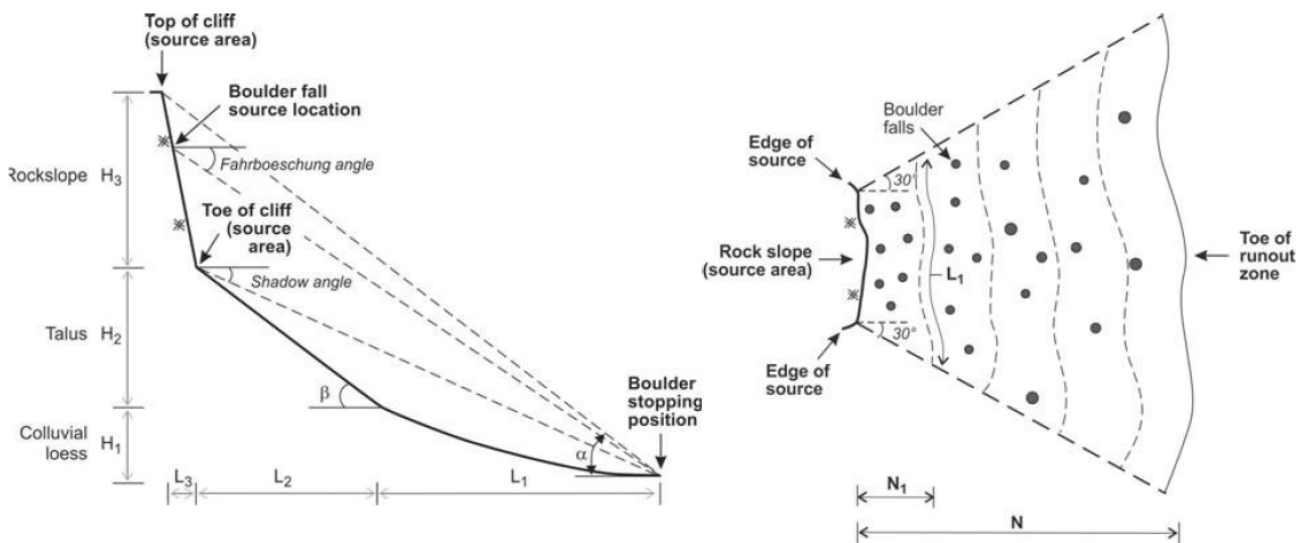


Figure 10 GNS runout distances



Figure 11 Rock fall analysis from controlled boulder release post September 2010 (from GNS Science). Rock falls on to Summit Road post 22nd February 2011 (GNS Photo-GTH_5998, from GNS Landslide Reconnaissance Flight Immediate Report).

Cliff Collapse

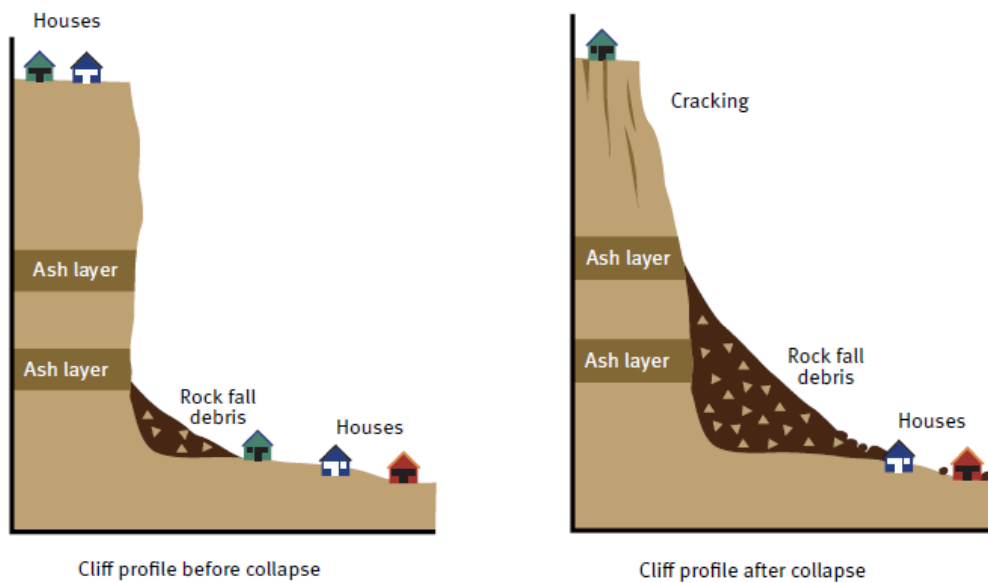


Figure 12 Image from URS



Figure 13 Redcliffs, Image from GNS

Map of cliff failures in the coastal suburbs of Christchurch (February and June 2011)



Stop 4 Vernon Terrace

The Hillsborough Valley has extensive fissuring on both sides extending from Ramahana Road through to Albert Terrace on the west and following the length of Vernon Terrace and Rapaki Road on the east. In general the fissure traces appear remarkably similar at any given location along the fissure trace. There is always an amount of lateral extension, in the order of 0.10-0.20m, and usually some vertical movement between 0.05-0.15m. The fissure traces on either side of the valley appeared at similar heights.

The Vernon Terrace fissures were observed to continue to creep for sometime following the Christchurch Earthquake (22 February 2011). Dellow et al. (2011) suggest that the fissures formed on a pre-historic landslide head-scarp. A detailed cross section of the Hillsborough Valley is provided in Figure 14

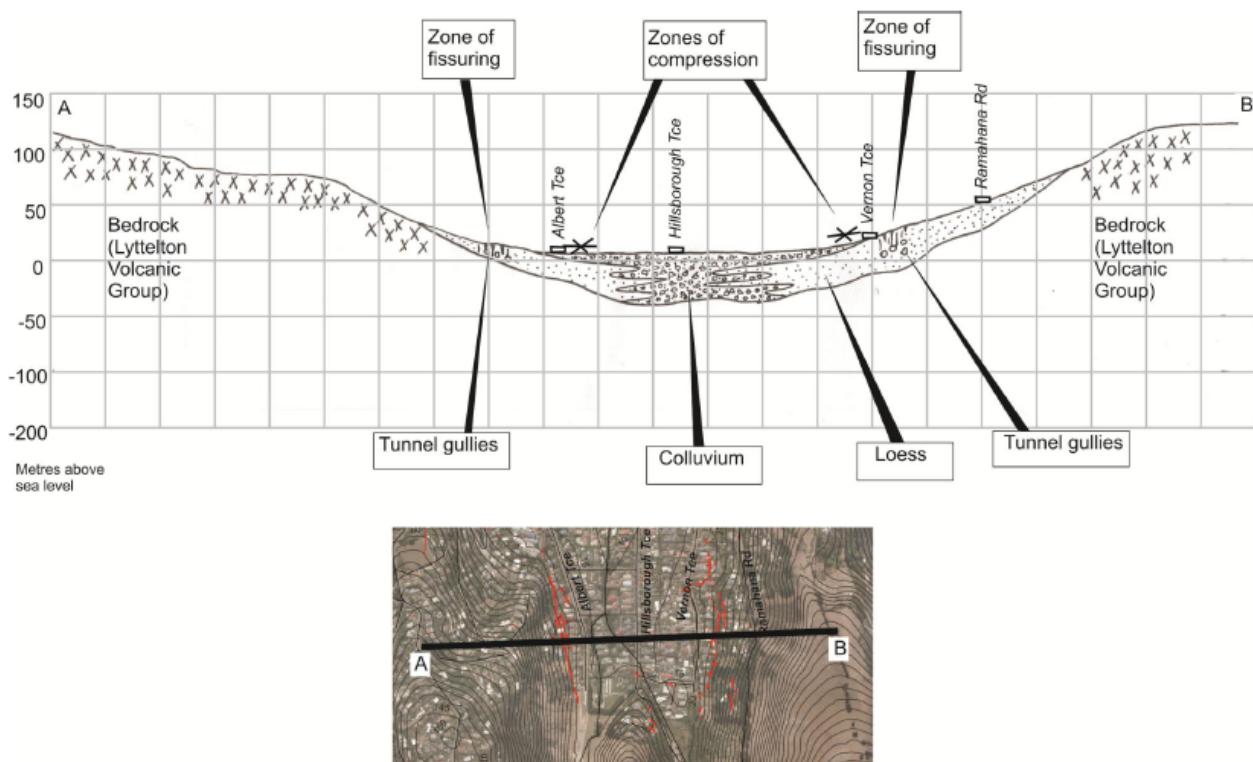


Figure 14 Schematic cross-section through Hillsborough Valley. Scale: natural scale, however size of fissures exaggerated approximately 5x, in order for clarity of observation. In reality they would extend only slightly into the loess layer. Bedrock and valley fill loess-colluvium mapped based on geological map in Brown and Weeber, 1992. (from Stephen-Brownie, 2012)

The fissure traces are predominantly discontinuous segments that follow a roughly contour-parallel orientation, extending for a distance of 500-600m, and coincide approximately with the boundary between the hill mantling loess deposits and the colluvial valley fill. Nearly every section of fissure trace with measurable extension is accompanied by lateral compression features in the valley floor below. These were commonly observed in sealed roads and kerbing where linear sections have been truncated. The extent of compression is comparable to the extent of lateral extension in the fissures above (See Figure 15). Fence offset along the driveways of Vernon Terrace indicates compression in the order of 700-800mm. The cumulative displacements across the tension cracks rarely exceed more than one metre (Dellow et al. 2011).

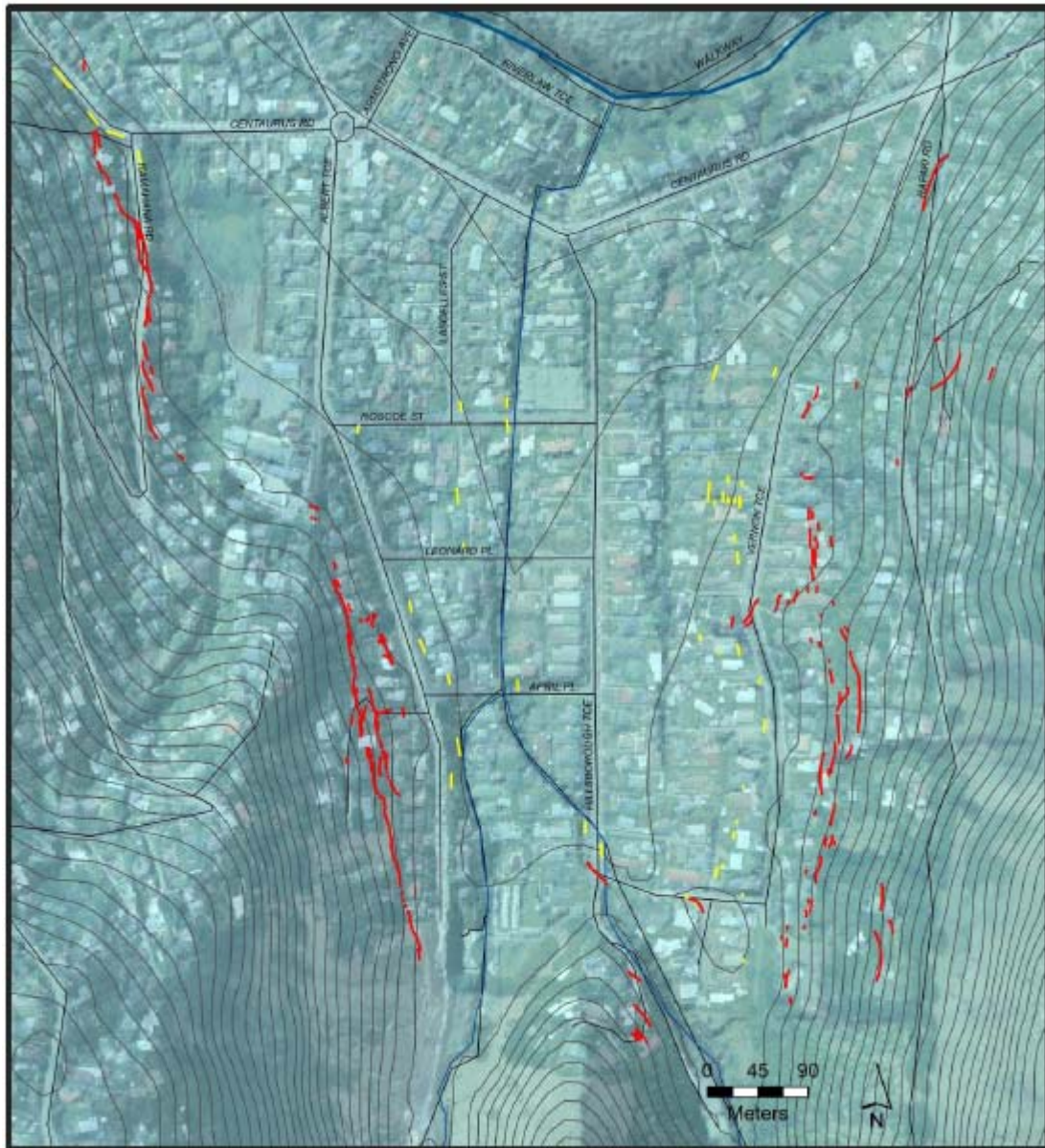


Figure 15 Areas of obvious compression in the Hillsborough Terrace valley. Compression features, usually parallel to fissure trace above, are shown in Yellow. (from Stephen-Brownie, 2012)

One feature of fissuring has been the contemporaneous formation of new springs and seepages in some valley floors. The Hillsborough Valley region has at least two dozen new springs which do not appear to be greatly affected by season or rainfall. The springs are located in three main groups; one at the western fissure; another along the eastern side of Albert Terrace; and the third about half way down Vernon Terrace on the western side of the road (Figure 16)



Figure 16 Map of known locations of springs, seepage and/or ponding issues in the Hillsborough Terrace valley area. Large blue dots show sites of flowing springs, small blue dots are areas of persistent seepage or boggy ground, and black dots show sites where ground water issues were reported but the extent is unknown by author (Stephen-Brownie, 2012). Red lines indicate the fissure trace. Spring data from H.Rutter (Aqualinc, 2012) and Stephen-Brownie's own observations. (from Stephen-Brownie, 2012).

Spring clusters in Vernon Terrace contain at least seven constantly flowing springs, with a further five nearby sites experiencing severe seepage/drainage problems. Multiple residents, in this group, reported the formation of 'pools' or small 'lakes' on their properties. Rainfall does have an impact on this spring area, as at least one pool site is said to dry out in extended dry weather, and others distinctly worsen after rainfall, implying that the ponding is the combined effect of both a raised water table, and constant spring flow. Residents first reported the appearance of springs in this area following the Darfield earthquake, with the Christchurch and June earthquakes each exacerbating the problem. Residents of 10 Vernon Terrace, report that they are pumping over 5760 litres per day from beneath one of their bedrooms. Water from these springs has a mineral content consistent with that typical of water which has been sourced from within the volcanic rocks of the Port Hills and are distinctly different from the city water supply which is sourced from the Canterbury Plains aquifers.

Stop 5 Porritt Park

Christchurch city is built at the coast of the Canterbury Plains on swamps, which have been mainly drained. In the western suburbs the deposits are mainly coarse gravels with the groundwater levels between 2-3 m below the surface. In the eastern suburbs near the coast, swamp, beach dune sand, estuarine and lagoon deposits of silts and fine sands become more prevalent. Groundwater level is relatively high across the city. The water table is about 5 m deep in the western suburbs, becoming progressively shallower eastwards, approaching ground surface near the coastline. To the east of the CBD, generally the water table is within 1.0–1.5m of the ground surface. The shallow soils within the top 10m are less than 4000 years old, and some are only a few hundred years old, which makes them vulnerable to liquefaction (Cubrinovski, Henderson & Bradley, 2012). The liquefaction resulted in settlement, lateral spreading, sand boils, and a large quantity of ejected silt mud and water ponding onto the soil surface. Many bridges crossing the Avon River suffered tilting in their abutments due to lateral spreading and loss of bearing capacity due to liquefaction. Fault and liquefaction induced subsidence, lateral spreading and heaving of the river-bed reducing channel volume, and settling of levees has significantly increased flood risk from the Avon River, requiring emergency levee construction and new storm water network construction.

Liquefaction was particularly extensive and damaging along the meandering loops of the Avon River, from the CBD to the estuary. In areas close to waterways, the liquefaction was often accompanied by lateral spreading. The most severely affected by liquefaction were the suburbs of Avonside, Dallington, Avondale, Burwood and Bexley. The soils in these areas are predominantly loose fluvial deposits of liquefiable clean fine sands and sands with non-plastic silts. Typically top soils (5-6m) are in a very loose state with CPT cone tip resistance (q_c) of about 2-4 MPa and soils at 6-10m 7-12 MPa. Lower resistances were often encountered close to wetlands.



Figure 17 Typical manifestation of liquefaction in residential areas (Fig. 19 from Cubrinovski et al. 2011)

Nearly 15,000 residential homes and properties were severely damaged due to liquefaction and lateral spreading, and more than half of those beyond economical repair. About 5,000 properties will be abandoned due to the infeasibility of repair (NZ Govt., 2011 in Cubrinovski et al, 2011). Examples of the results of liquefaction in residential areas are presented in Figure 17



Figure 18 Lateral spreading toward the Avon Rivers (Fig 24 from Cubrinovski et al. 2011)

Along the Avon River lateral spreading, causing horizontal displacement at the river bank in the order of several tens of centimetres to more than 2 m (Figure 18). Ground cracks associated with lateral spreading extended as far as 100-200m from the river.

Emergency stop banks, a total length of 17 km, were constructed up to 1.8m above mean sea level. Silty gravel was used for the construction material, as it was readily available and reasonably impermeable. Lateral spreading cracks were filled prior to stop bank construction.

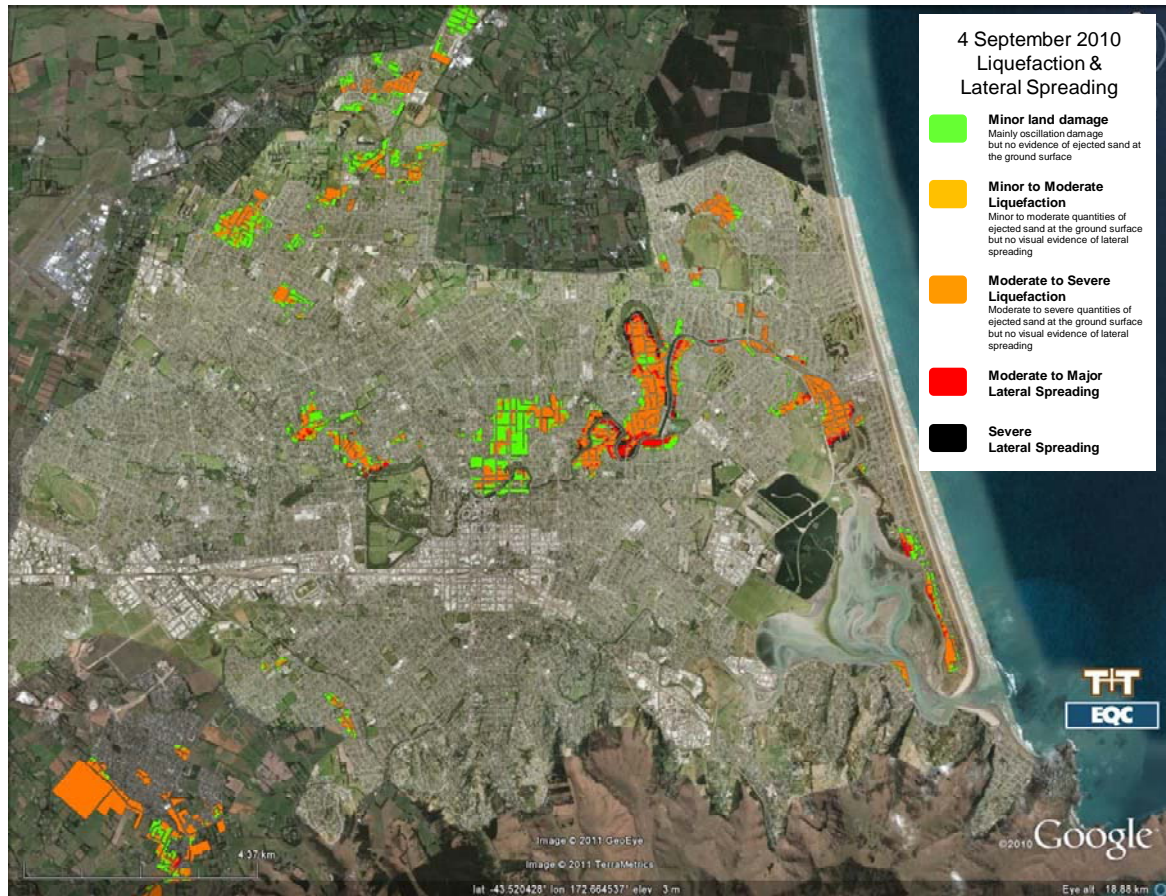


Figure 19 Land damage from the September 4 2010 earthquake (CERA and T&T Report)

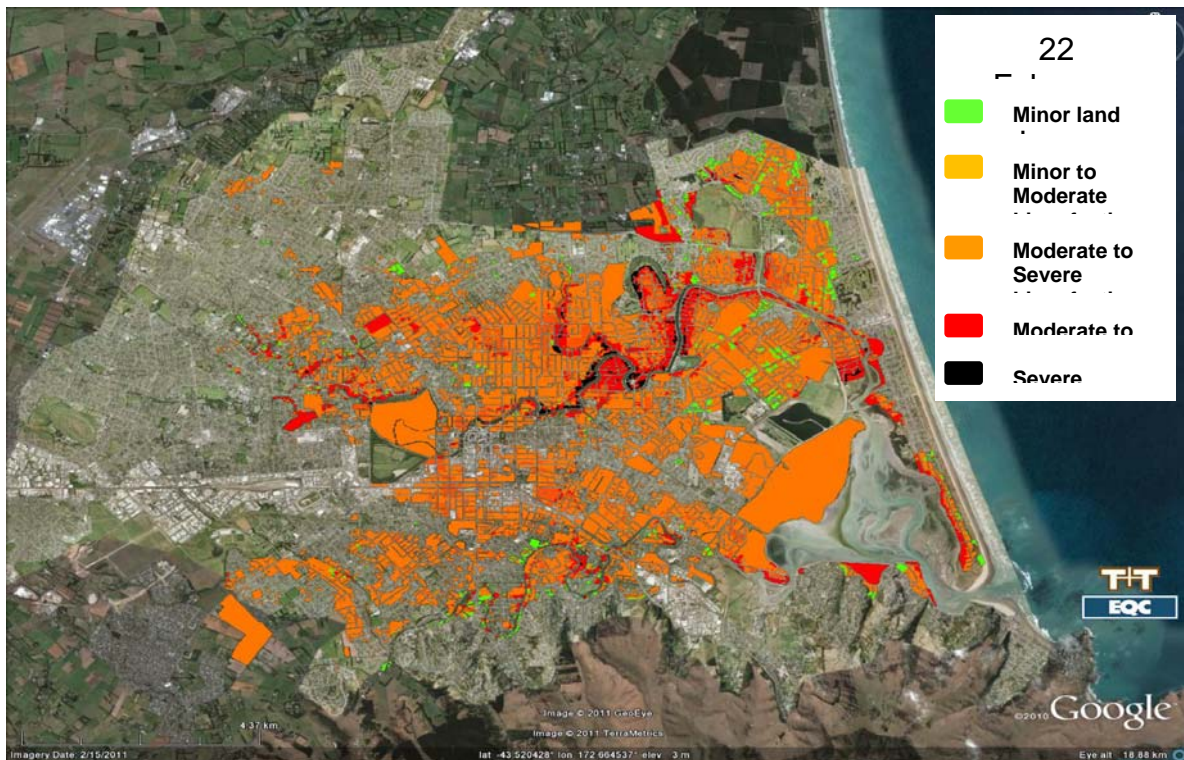


Figure 20 Mapped distribution of liquefaction induced land damage following 22 February 2011 earthquake.

Mapping of the liquefaction induced land damage indicated that the following areas were most affected by land damage (review from Jacka and Murahidy 2011, Tonkin Taylor):

- Riverside areas, particularly the inside of bends and historic meandering river channels through lateral spreading towards stream and rivers, causing much of the most severe land damage. This resulted in cracking, deformation and differential settlement of buildings, and the inundation of properties with ejected sand and water. Within river-loop areas or historic river channels further inland, property damage primarily comprised liquefaction-related differential settlement. Includes Avondale, Avonside.
- Estuarine and lagoonal areas where a mix of lateral spreading, ground oscillation, and liquefaction related differential settlement resulted in very severe damage to pipelines, the cracking and deformation of buildings, and property inundation by ejected sand and water. Includes Bexley, Brooklands, Redcliffs, Southshore.
- Inland loose alluvial deposits, where damage occurred due to ground oscillation, sand ejection, and liquefaction-related settlement. This has resulted in generally minor to moderate damage to buildings however, may have longer-term implications for building serviceability. Includes parts of Belfast, Bishopdale, Casebrook, Fendalton, Halswell, Hoon Hay, Redwood, Parklands, Richmond, and St Albans.

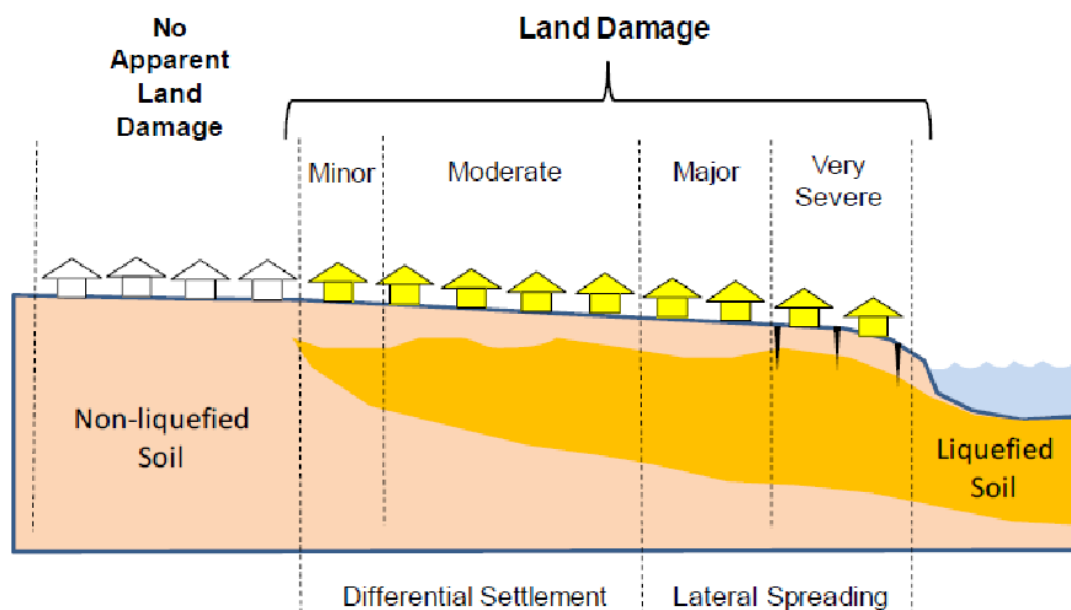
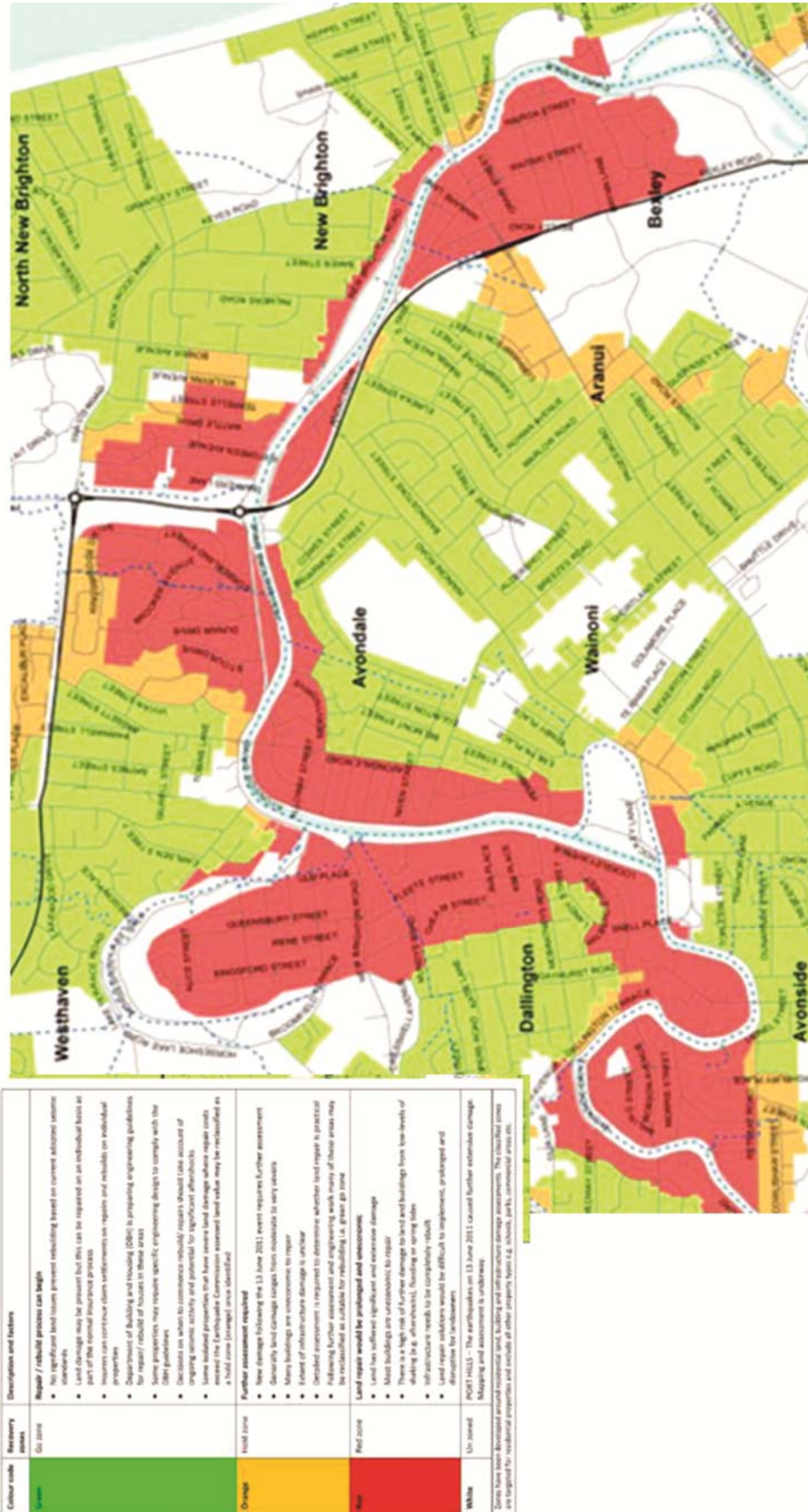


Figure 21 Schematic cross section of the spatial distribution of zones of land damage (Jacka and Murahidy 2011).

The widespread, severe liquefaction ground damage in predominantly eastern suburbs and the excessive economic and social cost required to remediate the land has led the central government recovery authority, (CERA), to rezone over 7,000 residential properties. The land will be retired from urban residential or commercial use in the short to medium term. A parallel process has occurred for properties on the Port Hills exposed to rockfall, landslide and cliff collapse hazards, which is currently on-going. This major rezoning has had significant implications for the future design (particularly during the accelerated rebuild phase) and configuration of lifeline networks in Christchurch.



Canterbury land information zoning map (CERA)

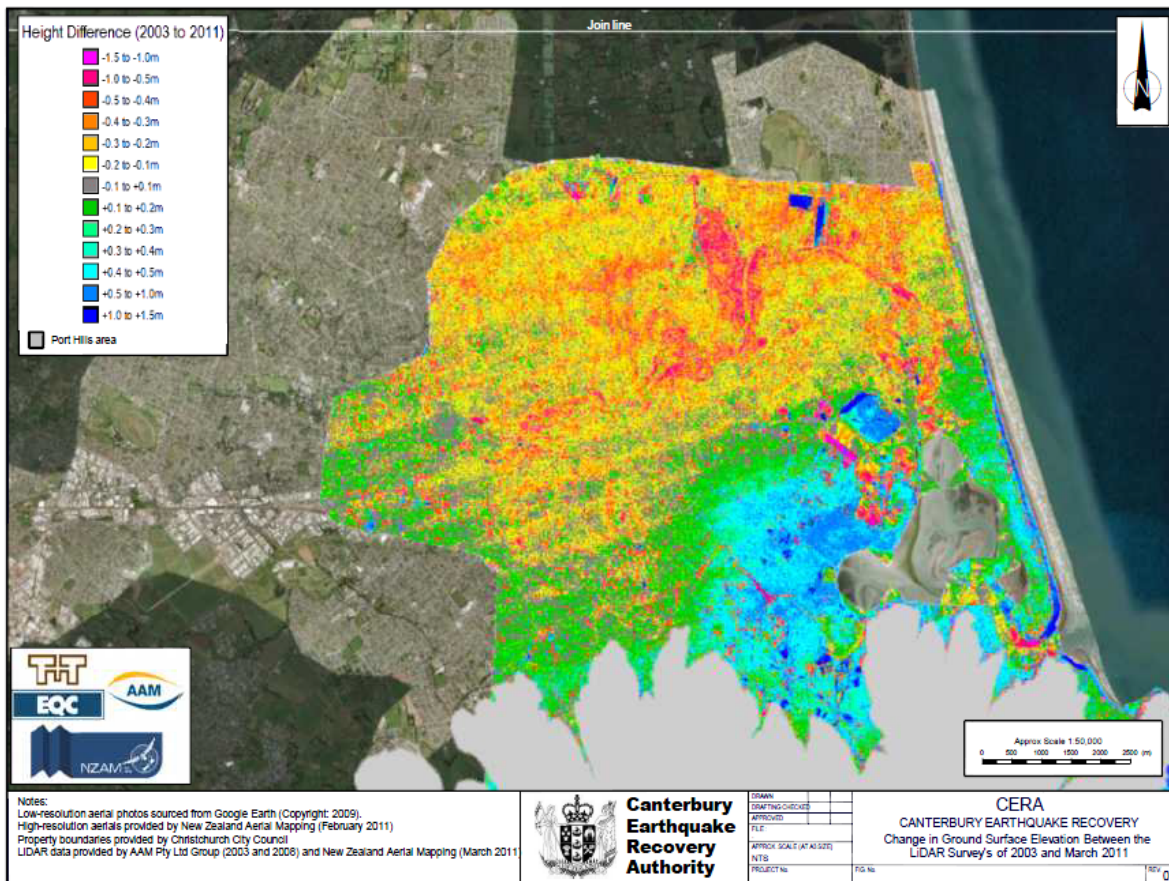
Following the geotechnical testing, analysis of the future flooding and liquefaction hazards, and the property and lifeline damage, land within Christchurch was categorised into 4 zones:

- Red Zone – This land is considered unlikely to be suitable for continued residential occupation for a prolonged period of time, as it has been subjected to significant land damage. It is also considered to have a high risk of further damage from low levels of shaking; and the success of engineering solutions for remediation are uncertain and uneconomic. The Crown has offered to either purchase the entire property at current rating value and assumes all the insurance claims other than contents; or purchase the land only, and homeowners can continue to deal with their own insurer about their homes.
- Orange Zone – Includes areas where engineers need to undertake further investigation prior to undertaking repair or remediation work.
- Green Zone – This includes the majority of greater Christchurch, with land considered suitable and economic to repair. This has since been divided into 3 subcategories for purposes of foundation selection.
- Technical Category 1 - Future land damage from liquefaction is unlikely.
- Technical Category 2 - Minor to moderate land damage from liquefaction is possible in future significant earthquakes.
- Technical Category 3 - Moderate to significant land damage from liquefaction is possible in future significant earthquakes.
- White Zone – these areas are still being mapped or tested, or are not residential land.

The total number of red zoned properties, as at 18th May 2012, numbered 7200.

Stop 6 Dallington (Drive past and through)

Driving through Dallington along New Brighton Road, and other detours opposite Porritt Park, reminds us that the eastern suburbs have been changed forever – and that the focus of EQC and individual insurers on the west of the city has still to address the obvious concerns of many residents. In Dallington there has been widespread lateral spreading leading to property abandonment, and the land has dropped by half a metre or more leading to a major inundation risk. This is a good opportunity on the last part of the Field Trip to remind ourselves of the geological controls on damage to the flat land of Christchurch, particularly along the river corridors. We knew about the liquefaction risk more than 30 years ago, but we continued to infill and develop land that with hindsight was unsuitable – or at least required much more robust design measures. This issue is not just a Christchurch one.....



Ground Difference Map: Change in ground surface elevation between 2003 and March 2011 (from CERA).

Acknowledgements

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