Canterbury Earthquakes 2010/2011
Port Hills slope stability: Geomorphology mapping for rockfall risk assessment

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DISCLAIMER

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EXECUTIVE SUMMARY

Christchurch City Council requested GNS Science to carry out geomorphic mapping of the near-surface materials and processes present in the Port Hills of Christchurch. The purpose of this work is to provide information relating to near-surface geological materials and the geomorphic processes that formed them. These data are needed as inputs to the rockfall hazard and risk assessments currently being carried out by GNS Science for Christchurch City Council. This document and the accompanying maps provide the results of the geomorphic mapping of rockfall hazard zones for the Port Hills identified by GNS Science (Massey et al. 2012a,b). The area has been mapped in detail (at a scale of about 1:500) using aerial photograph mosaics and satellite images, with limited field verification. Three attributed Geographic Information System (GIS) layers contained within a geodatabase have been produced: two polygon layers [*interpreted materials* and *genesis*] and a polyline layer [*morphology*], digitised directly from aerial photograph mosaics and satellite images. This report contains explanatory descriptions and photographs of the mapping units in the GIS layers, and copies of the maps produced.

1.0 INTRODUCTION

Christchurch City Council requested GNS Science to carry out geomorphic mapping of the materials and processes present in the Port Hills of Christchurch. The purpose of this work is to provide information relating to near-surface geological materials and the geomorphic processes that formed them.

These data are needed as inputs to the hazard and risk assessments carried out by GNS Science for Christchurch City Council (Massey et al. 2012a,b). The purpose of this report is to provide the results of the geomorphological mapping. The objectives of this work are to provide maps:

1. to facilitate the two- and three- dimensional numerical rockfall modelling commissioned by Christchurch City Council and the Canterbury Earthquake Recovery Authority (CERA);
2. showing the locations of past (pre 4th September 2010) rockfalls, cliff collapses and landslides in the Port Hills;
3. for use in the ground truthing of the rockfall and cliff collapse hazard zones contained in Massey et al. (2012a,b).

The methodology adopted is similar to those used internationally (e.g. Griffiths, 2002; McMillan and Powell, 1999).

The mapping has been carried out at a scale of about 1:500, using aerial photograph mosaics, satellite images and digital terrain models, with limited field verification.

The report contains explanatory descriptions and photographs of the mapping units in the *interpreted materials* and *genesis* Geographic Information System (GIS) layers, and the methodology used to produce them. Descriptions of the units and the criteria used to map them are presented in Appendices A-C, and the maps are presented in Appendix D.

2.0 MAPPING METHODOLOGY

Analysis was performed by assessing landforms (geomorphology), interpreting their origin or genesis and making assumptions as to the underlying material, as outlined below. Three attributed GIS layers have been produced: two polygon layers [*interpreted materials, genesis*] and a polyline layer [*morphology*]. These layers were produced by analysis and digitising directly from aerial photograph mosaics and satellite images, with limited field verification.

The digitising has been registered most rigorously to the New Zealand Aerial Mapping (NZAM) aerial photograph mosaic [NZAM_mosaic_03_03_2011], flown about 10 days after the February 22nd 2011 Christchurch Earthquake, and which has a 10 cm pixel (ground) resolution. Other useful images include the post-Darfield Earthquake (4th September 2010) GeoEye image [Christchurch_GeoEye_4-9-10-All_data_Ortho] and the post February 22nd 2011 image [geoeye_27feb11.ecw].

In many areas where there has been extensive modification of the landscape through building/construction, older stereo pairs of aerial photographs (1940's – 1980's) were also used. These were interpreted using a stereoscope, were rectified onto the base maps using ArcMap GIS software, and then digitised and attributed. Digital terrain models constructed from Light Detecting and Ranging (LiDAR) data (2011a, 2011c) were also used to interpret geomorphic features.

Geomorphological mapping of the Port Hills using the aerial photographs and LiDAR digital terrain model was completed in April 2012. This included all of the sectors defined by the Port Hills Geotechnical Group, excluding Diamond Harbour.

Ground verification of mapped units in the pilot study areas was undertaken in December 2011 and January 1012. The remainder of the Port Hills area, as outlined above, was concluded on 2-4 May 2012. Ground verification consisted of driving the roads in the Port Hills (Figure 1), especially in areas where extensive modification of the ground surface has taken place through residential construction. Outcropping materials were noted on 1:5000 scale printed maps (see Figure 2 for locations). The results of the field verification required some editing of the initially mapped polygons, typically the addition of small regions of materials not obvious from the aerial photography. These tended mainly to be small outcrops of rock and/or loess exposed in road cuttings. Also, the extent of loess along the Summit Road had been overestimated; even though the surface expression of these high elevation areas was essentially featureless on the photographs, we found that most road cuts were into rock, commonly with a thin cover of colluvium. Changes to the polygons in the *interpreted materials* and *genesis* layers have been made to reflect the data collected in the field. Figure 3 shows the overall confidence in the mapping of the interpreted materials.

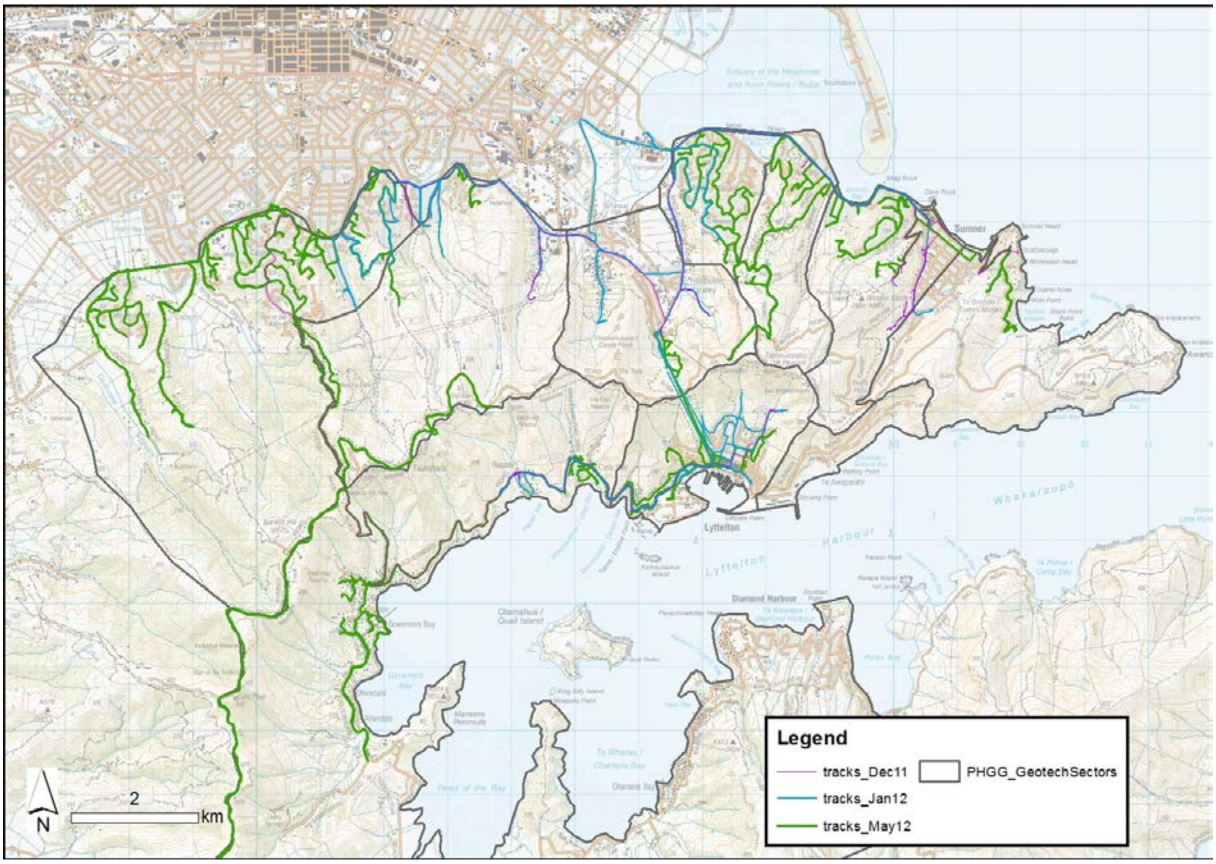

Figure 1 GPS track log of ground verification route. Background map from Land Information New Zealand Topo50 series.

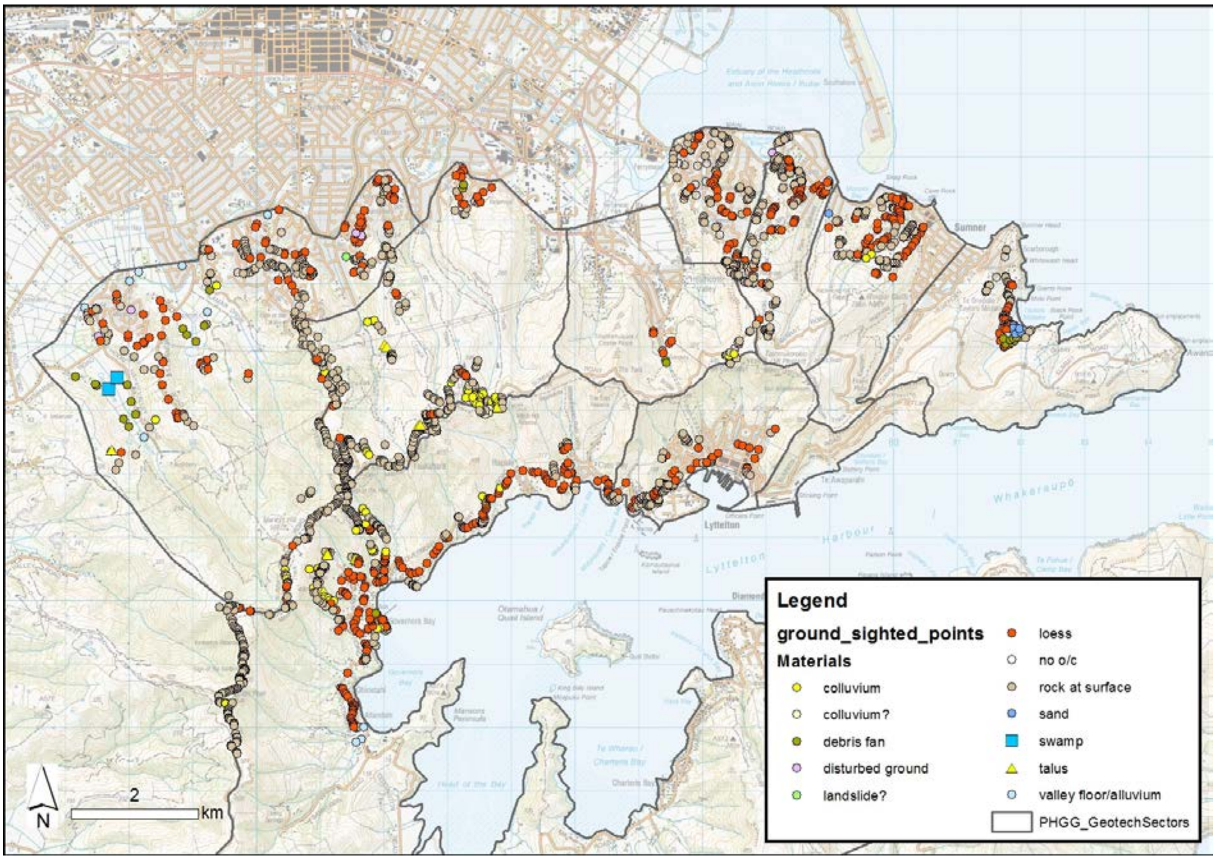

Figure 2 Locations of outcropping materials noted during April 2-4 ground verification.

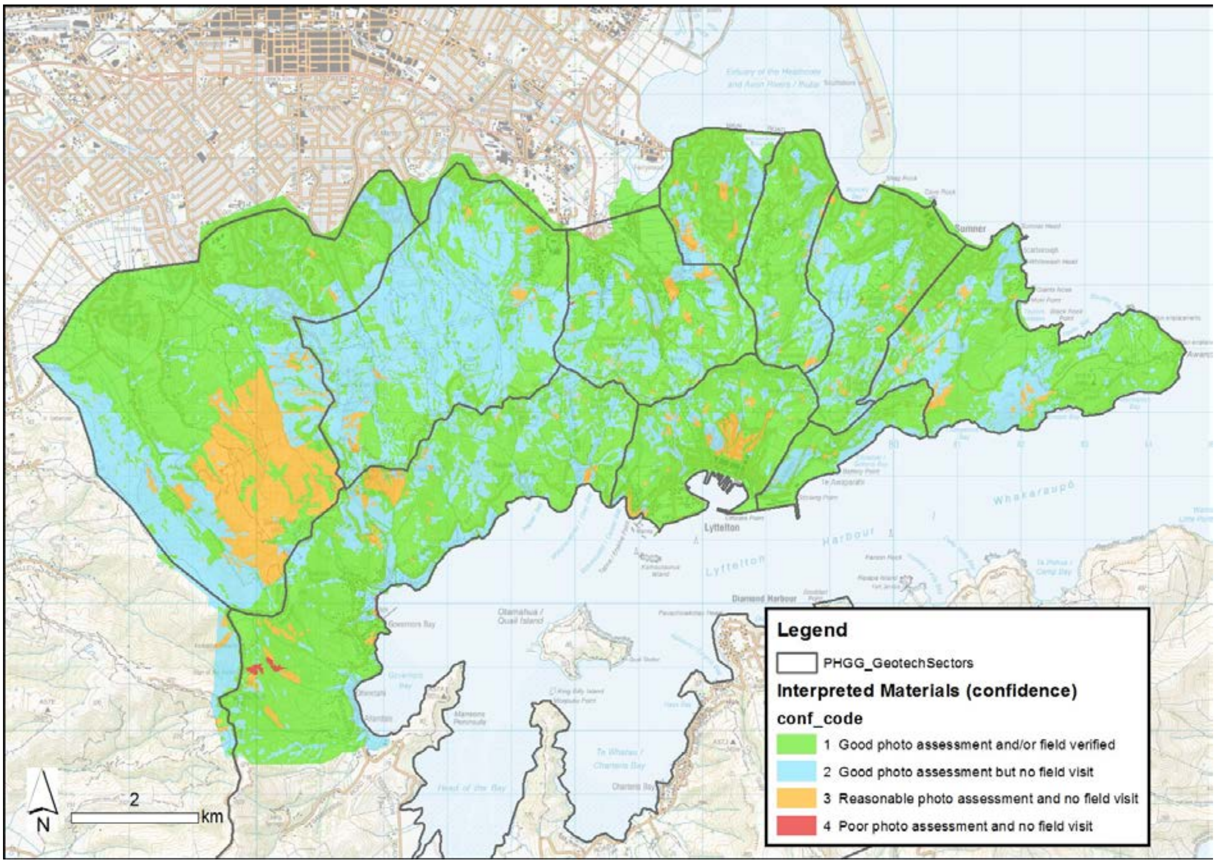

Figure 3 Confidence of interpreted materials mapped in the Port Hills.

2.1 GEOMORPHIC MAPS

A representative result of the geomorphology mapping, as provided in Appendix D, is shown on Figure 4. The map index and page numbering (inset map) is the same as the rockfall risk zone maps produced by Massey et al (2012b).

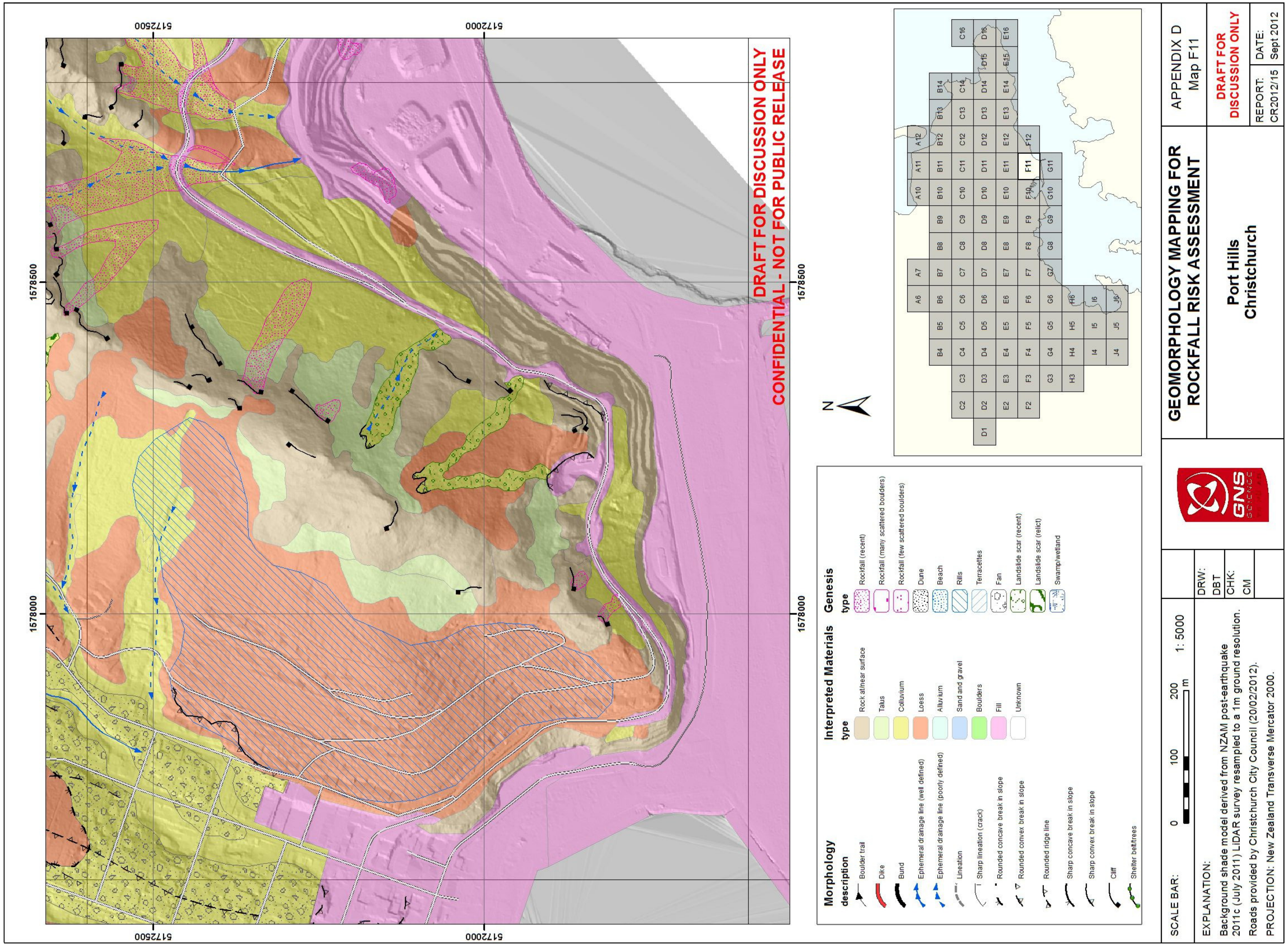

Figure 4 Example of geomorphic maps presented in Appendix D. The symbols in the legend are the same for the diagrams in sections 2.2.1 to 2.3.6. The area shown is just to the east of Lyttelton.

2.2 MORPHOLOGY GIS LAYER

The *morphology* layer is a polyline shapefile containing linear features such as drainage lines, recent landslide scarps, cliffs and significant breaks in slope, which are directly observable from the images. Categories are described in Appendix A.

2.3 INTERPRETED MATERIALS GIS LAYER

The *interpreted materials* GIS layer contains geological information about the substrate or regolith. The layer has been categorised into several mapping units, using aerial photographs and LiDAR datasets. The mapping units are based on geomorphic criteria and were chosen to provide the data needed for rockfall hazard risk assessment of the Port Hills (Massey et al. 2012b). They are characterised as follows:

- bare ground with high-contrast and interlocking rock blocks of varying sizes is **rock at/near surface** (r). The bare ground may in part be thinly mantled e.g. by talus, colluvium, or loess;
- high-contrast areas composed of smaller interlocking blocks, boulders and cobbles is **talus** (t);
- actively accumulating gullies and gentler hill slopes are underlain by **colluvium** (c).
- rills and terracettes are formed in **loess** (e);
- flat ground in valley bottoms is underlain by **alluvium** (al)
- flat coastal ground (commonly built upon) is underlain by **sand and gravel** or **boulders**;
- built-up areas are typically underlain by **fill** (n);
- areas unable to be determined from images and which have not been field verified are mapped as **unknown**.

These units are described, with representative illustrations for the four most extensive map units, in sections 2.3.1 to 2.3.9. Details of the mapping criteria for each unit are given in Appendix B.

Illustrations for each key unit (Figure 5 - Figure 10) comprise an un-annotated aerial photograph (top left), an aerial photograph overlain by the GIS *interpreted materials*, *morphology* and, where appropriate, the *genesis* layers (top right; see Figure 4 for legend), and a ground-based photograph (bottom). Arrows on the un-annotated photograph are approximately the view direction of the ground photo. The scale bar on all aerial photographs is 50 m and they are oriented with north towards the top. Topographic contours, where shown, are at 5 m intervals. Approximate grid references for locations are given in New Zealand Transverse Mercator 2000 projection.

2.3.1 Rock at/near surface (r)

Layered flows of volcanic rock form prominent, steep to vertical cliffs in the Port Hills and the wider Banks Peninsula area (e.g. Figure 5). Rocks also crop out on rounded spur/ridge tops, sometimes with a thin covering of loess and/or colluvium. The “slope greater than 35 degrees” terrain analysis layer agrees well with the distribution of cliffs and bluffs, but rock can also occur at the surface on gentler terrain. Thus, while most areas of slope >35° will be rock at the surface (apart from a few cliffs cut into loess), it will not include all areas of exposed rock.

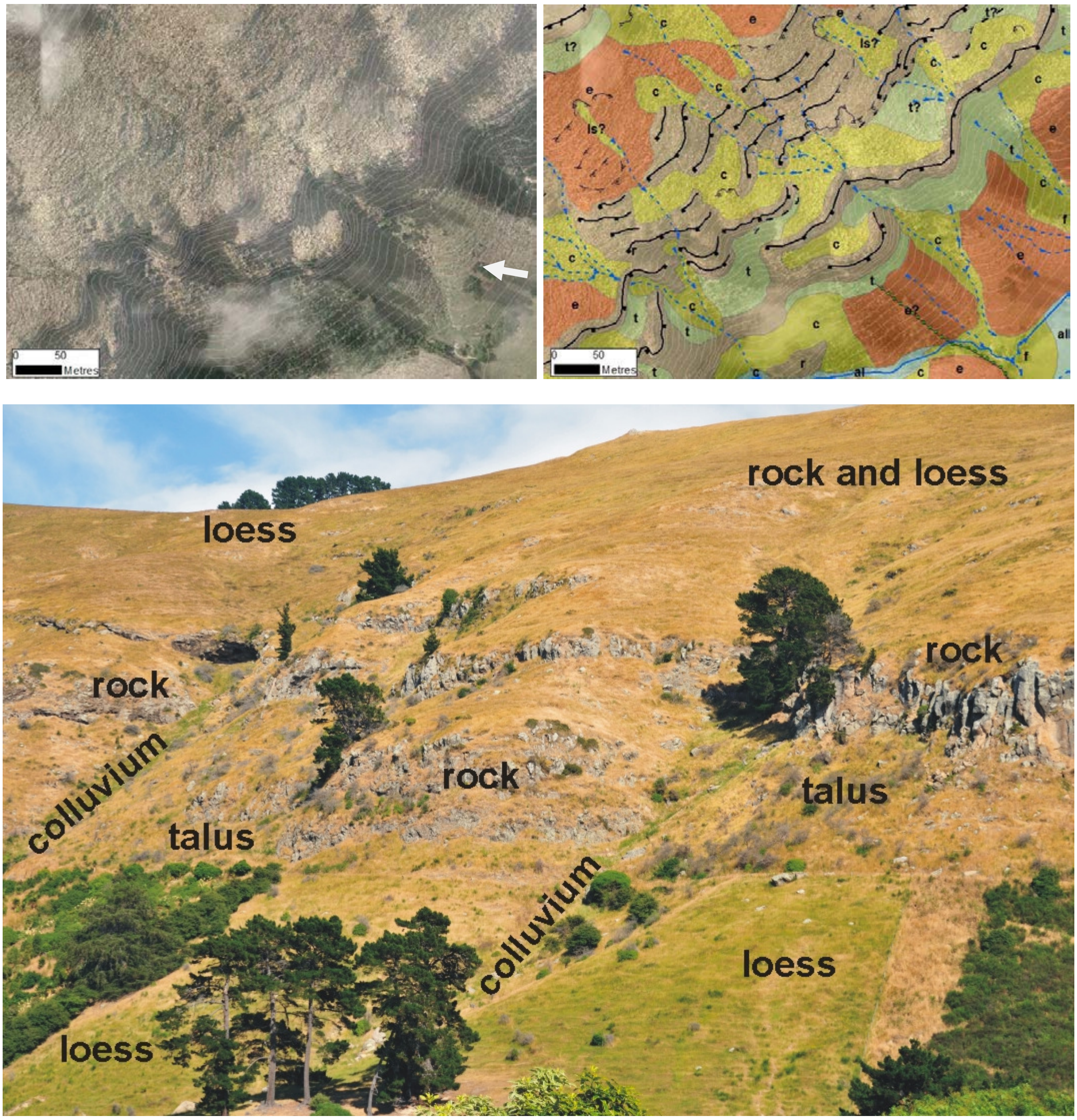

Figure 5 Rock at/near surface appears as blocky, high-contrast areas on the images and usually forms steep cliffs, typically with a talus apron at the base. These bluffs are near Wakefield Street (Grid Reference 1579700/5174400).

2.3.2 Talus (t)

Scree and talus consisting of loose blocks of remobilised rock commonly form aprons at the bases of steep cliffs and other rock exposures (e.g. Figure 6). This unit includes some of the more extensive recent rockfall deposits (see below). Areas of talus merge with colluvium and therefore boundaries are only approximate. Talus commonly forms steeper slopes than colluvium, and there is usually a concave break in slope at the boundary between the two.

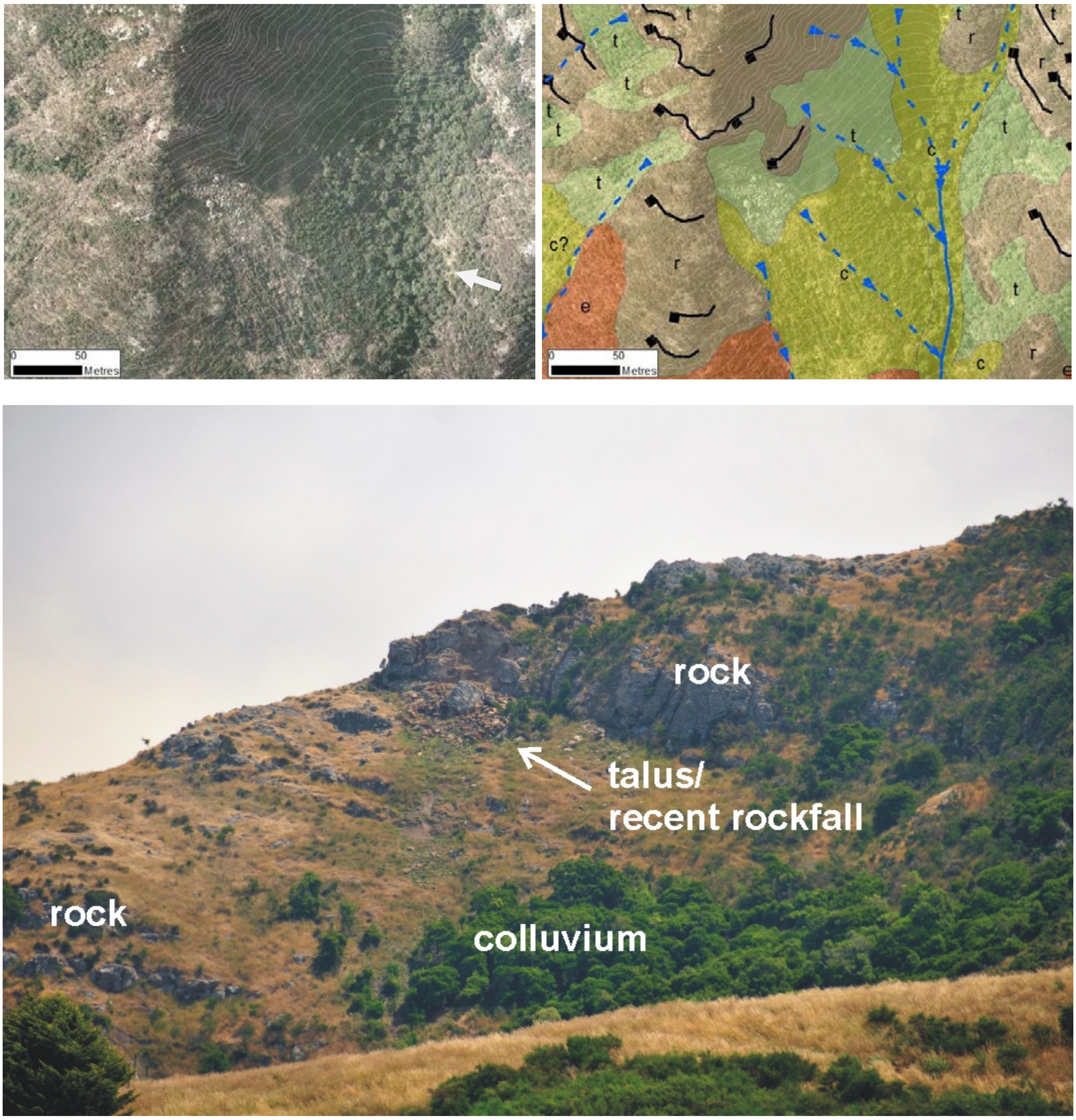

Figure 6 Talus slopes below rock cliffs about 350 m southwest of Mt Pleasant. These fresh rockfalls occurred during the February 22nd 2011 Christchurch Earthquake, but the underlying apron has been built up from many such events (Grid Reference 1577900/5173400).

2.3.3 Colluvium (c)

Colluvium and shallow landslide (debris flow) debris has collected in many gullies and on steeper faces below cliffs (e.g. Figure 7). It includes undifferentiated shallow landslide debris in chutes (trails) and on steep faces, and the run-out area of shallow loess slides and/or debris flows. Colluvium is composed mainly of remobilised soil, silt (loess) and gravel to boulder sized rock clasts. It is generally the source for materials building the areas mapped as debris fans (see below).

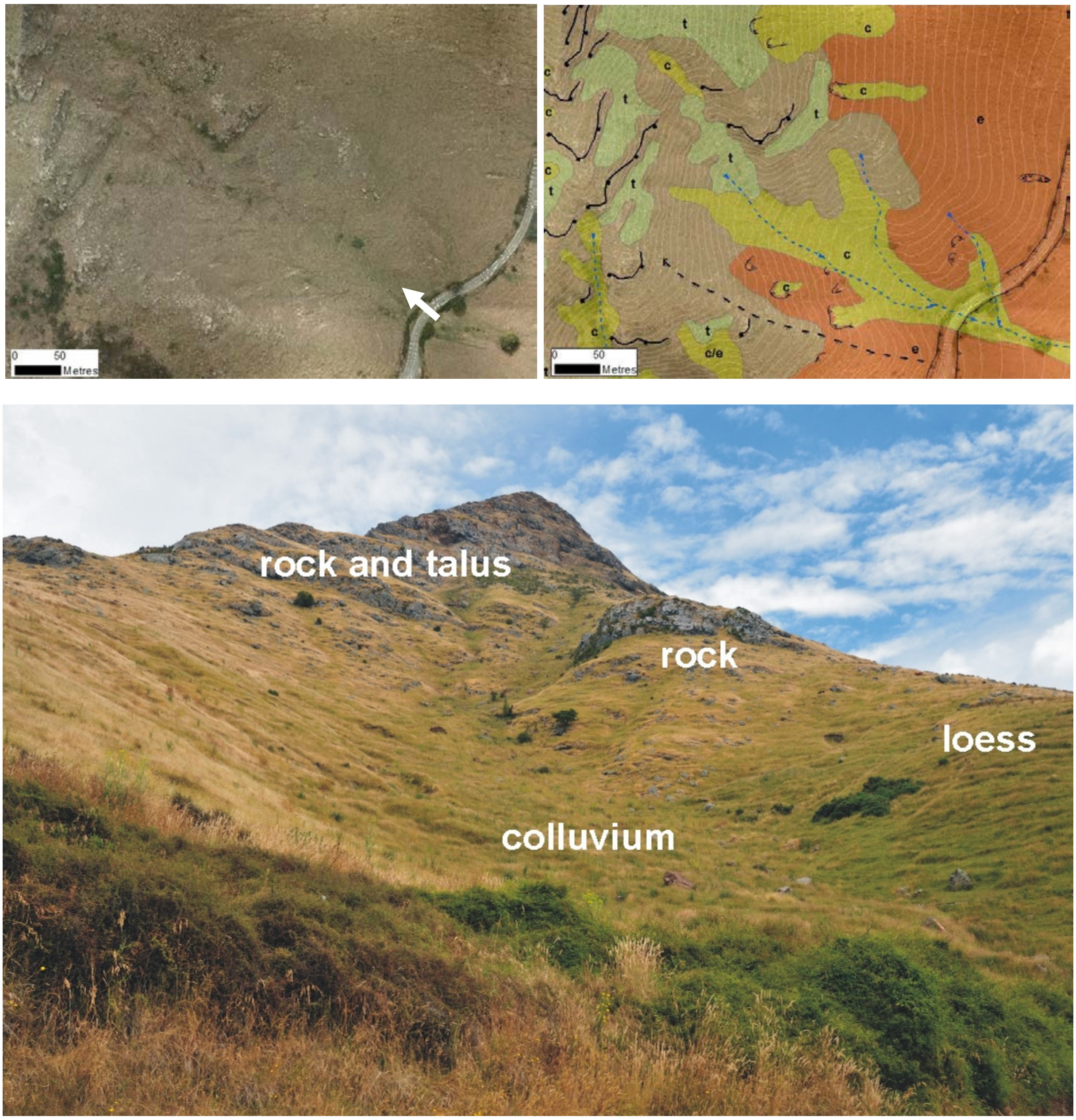

Figure 7 Colluvium and scattered boulders in a gully southeast of the main hill (405 m high) at Rapaki (Grid Reference 1573600/5171900).

2.3.4 Loess (e)

Loess is present as a mantling deposit of silt to fine sand on many of the mid-lower elevation slopes (e.g. Figure 5, Figure 7, Figure 8, Figure 9, Figure 10), and on the flat plateaus at the tops of ridges. Loess deposits on the Port Hills may be several metres thick; it typically becomes rilled by erosion on steeper slopes.

Figure 8 Loess deposits commonly have a distinctive geomorphic expression and erode to form bad-lands topography, as at Wakefield Street (left) (Grid Reference 1580400/5175300), or more commonly rills and terracettes, such as at Rapaki (right) (Grid Reference 1573900/5172000). Note also the large boulders lying on the surface and the break in slope to the debris fan on the right.

2.3.5 Alluvium

Alluvium is interpreted to underlie flat valley floors and coastal areas adjacent to headlands. Deposits include boulders, gravel, sand, silt and peat. In reality, much of this mapping unit has been modified to some extent by fill and/or drainage works.

2.3.6 Sand and gravel

Flat ground adjacent to the coast in sheltered areas is interpreted as having formed by marine and marginal marine processes, and therefore underlain by sand and gravel. The majority of this mapping unit has been built upon as it provides ideal land for urban development.

2.3.7 Boulders

Exposed coastal land especially below rock cliffs is commonly comprised of boulders. The boulders are typically about 1-5 m in diameter and are likely to be talus deposits that have been sorted by wave action.

2.3.8 Fill

Land modified by human impact where it is not possible to accurately assess the underlying material is mapped as fill. In many areas an attempt has been made to determine the nature of the substrate, which is attributed accordingly. This unit includes both man-made fill (boulders to gravel) and in some cases excavated ground, where the distinction cannot be made.

2.3.9 Unknown

Some areas have not been classifiable into material type. This is due mainly to cloud or tree cover obscuring the ground surface, and/or the contour and LiDAR models not providing enough resolution to interpret the landscape-forming material.

2.4 GENESIS GIS LAYER

The *genesis* layer was digitised to map the surface geomorphological processes, many of which are directly observable from the images. These are described in sections 2.3.1 to 2.3.6 and are summarised in Appendix C. Mapped processes are not mutually exclusive – they may overlap spatially (e.g. scattered boulders may overlap an area of loess rilling).

2.4.1 Rockfall

There are many areas of rockfall in the Port Hills, ranging from recent to older deposits. These have been subdivided into:

Rockfall (recent)

Recent rockfalls are interpreted as having occurred as a result of the Canterbury earthquakes. They are denoted by: 1) concentrated areas of boulders (including some retaining wall collapses) which are demonstrably absent on pre- 22nd February 2011 images; and/or 2) concentrated area of boulders intermixed with soil; and/or 3) concentrated area of boulders with fresh/unweathered appearance that may be traced up-slope to unweathered/freshly-exposed rock face; or 4) areas of boulder trails and flattened vegetation/grass. Source area is almost always in rock.

Rockfall (many scattered boulders)

Area occupied by "many" boulders, typically close to a rock source. The boulder concentration is generally 1 every 2-10 m.

Rockfall (few scattered boulders)

Area occupied by a "few" boulders, typically close to a rock source. The boulder concentration is generally 1 every 10-50 m.

2.4.2 Dune

Sand dunes are preserved across some of the low topography at valley mouths (e.g. Sumner, Monck's Bay, Taylor's Mistake) adjacent to the coast. The dunes are composed primarily of well sorted sand.

2.4.3 Beach

Beach deposits include areas of sand and gravel, and boulders. These typically form flat ground adjacent to the coast, and sand or boulder beaches on headlands exposed at low tide.

2.4.4 Rills

Tunnel-gully erosion and rilling forms multiple, sub-parallel channels typically 1-5 m deep, and deeper erosion forms bad-lands canyons. These erosion features are indicative of loess deposits. Rilling commonly occurs on mid-gradient slopes formed in loess and is usually absent on ridge crests.

2.4.5 Terracettes

Terracing by stock commonly forms in steeper topography underlain by loess. These terracettes are manifest as narrow terraces (2-5 m apart in map view) with low risers (between about 1 and 2 every vertical metre).

2.4.6 Fan

Fans, consisting of multiple debris flows of remobilised loess, colluvium and minor alluvial gravel (i.e. colluvium), commonly develop below the steeper valleys (e.g. Figure 9). These fans are distinguished from areas of undifferentiated colluvium mainly by their conical or lobate shape and are interpreted as areas of deposition. The fan "apex" points towards the source area, which is typically a side valley formed in steeper terrain where colluvium, talus and loess have previously accumulated.

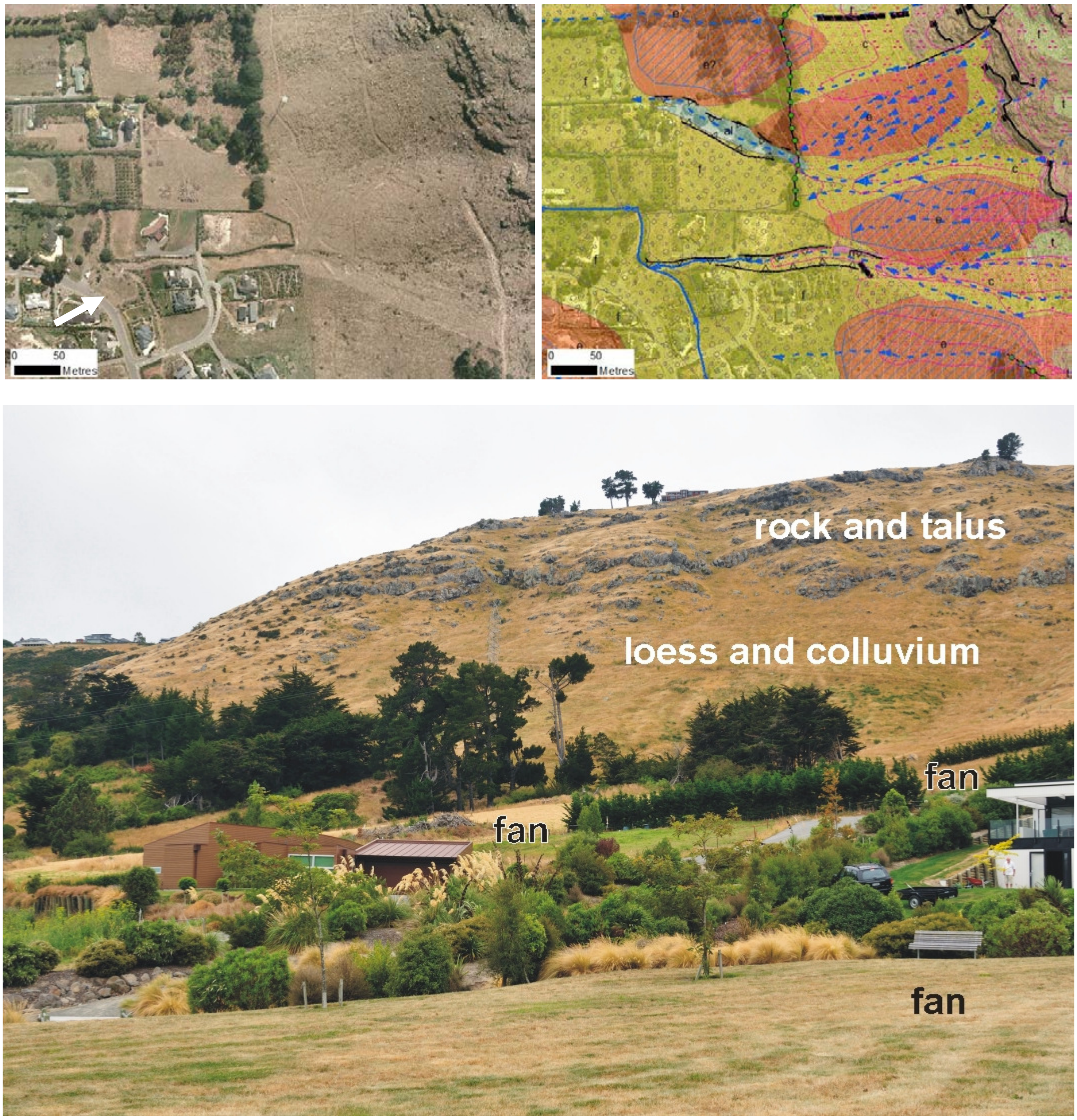

Figure 9 Colluvial fans forming gently dipping surfaces below steep rock cliffs in the Heathcote Valley (Grid Reference 1577100/5175000).

2.4.7 Landslide scar

The term “scar” relates to the landslide source area and associated deposits. These are indicative of mass-movement processes. Deep-seated landslides are relatively uncommon on the Port Hills; only a few minor rotational slides and slumps have been noted. Adopting the classification of Cruden and Varnes (1996), the vast majority of “landslides” in the Port Hills are debris flow or earthflow type (e.g. Figure 10), involving relatively shallow slides (several metres deep) and slumps initiated in loess and/or colluvium. The landslide deposits therefore, are typically broken up mixtures of the materials in which they originated. Landslide scars are classified in the *genesis layer* as “recent” or “relict”.

Landslide scar (recent)

For recent landslides, where the headscarp and debris areas can be differentiated, deposits are mapped as colluvium and the scarp area is mapped as the source material in the interpreted materials layer.

Landslide scar (relict)

Relict landslide scars include potentially older deposits where there is reason to suspect a landslide (e.g. hummocky topography), but which cannot always be attributed directly to a source area and the scarp may have been degraded.

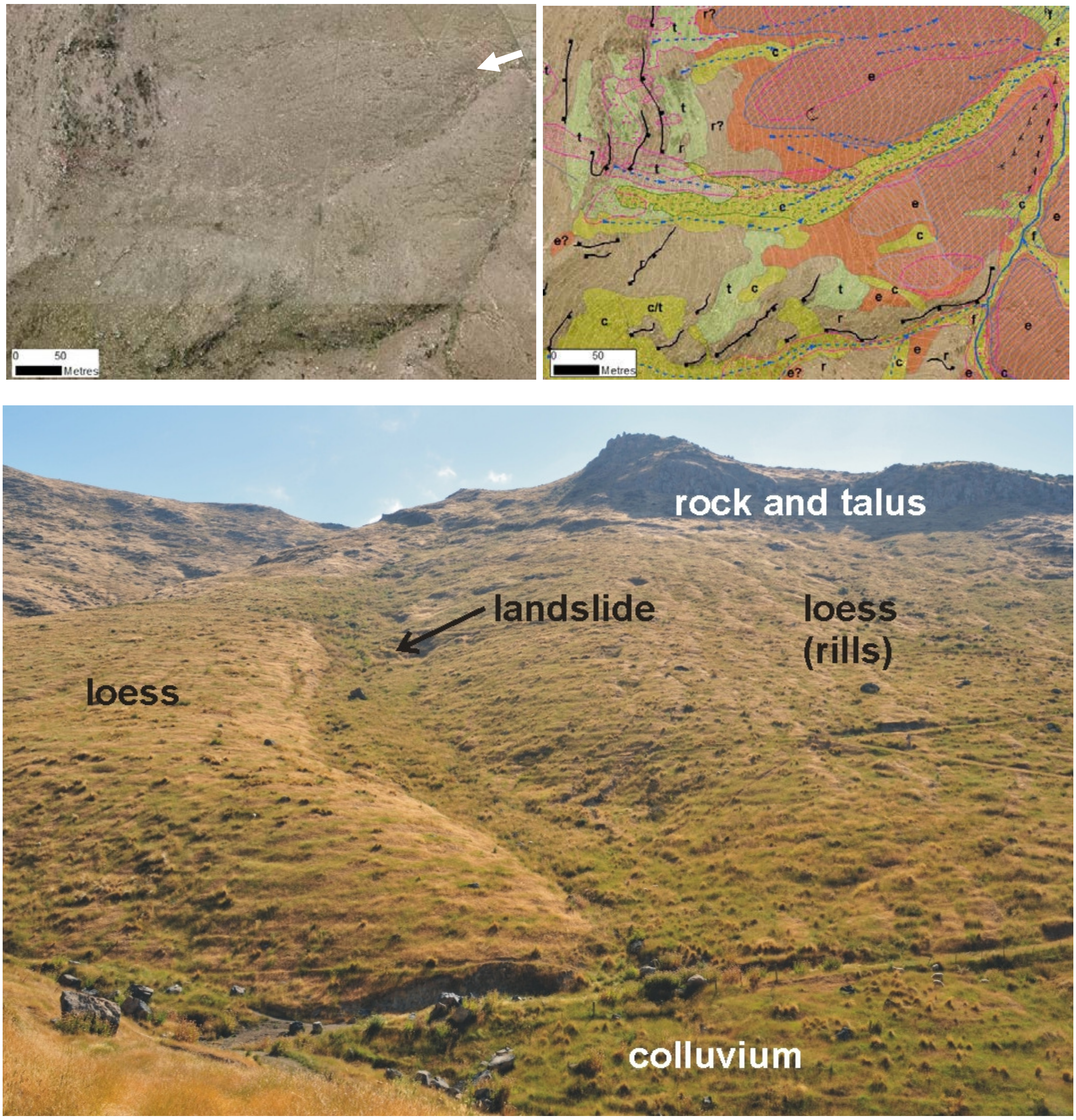

Figure 10 A landslide of shallow earthflow type in the Horotane Valley fills the small gully in the centre left. The rounded ridges on either side consist of loess. Note also the large boulders on the valley floor, many of which have fallen from Castle Rock (to the left, out of the picture) (Grid Reference 1575000/5174300).

2.4.8 Swamp/wetland

Few areas of swamp remain; some were noted on older aerial photographs, but most have been drained and filled in. Deposits include peat and to a lesser extent gravel, sand and silt.

3.0 ACKNOWLEDGEMENTS

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APPENDIX 1: MORPHOLOGY LAYER DESCRIPTION

Fields	
description	Feature observed on images (see below).

Description	Appearance
Boulder trail	Line or series of indentations where individual boulders have rolled or bounced down slope; not mapped everywhere.
Dike	Steep, linear outcrops of rock which do not topographically conform to being part of a gently dipping plane (e.g. as for a bed/lava flow).
Bund	Man-made earth wall.
Ephemeral drainage line (well defined)	Streams and gullies with a well-defined drainage; these may be permanent watercourses in some cases.
Ephemeral drainage line (poorly defined)	Streams and gullies with a poorly defined drainage, including selected rills.
Lineation	Linear feature resembling fault or discontinuity in bedrock; alternatively these could be dikes.
Sharp lineation (crack)	Sharply-defined linear feature. Typically seen where cutting across roads, parks and other modified ground. Interpreted as cracks related to settling, slope instability or lateral spreading during the 22nd February 2011 Christchurch earthquake.
Rounded concave break in slope	Smooth change from steep topography above to gentle topography below.
Rounded convex break in slope	Smooth change from gentle topography above to steep topography below.
Rounded ridge line	Gently dipping ridge lines with little or no rock outcrop.
Sharp concave break in slope	Sharp change from steep topography above to gentle topography below.
Sharp convex break in slope	Sharp change from gentle topography above to steep topography below.
Cliff	Steep to vertical rock faces, typically contiguous in sub-horizontal bluffs formed from gently dipping individual lava flows. Some cliffs are also cut into loess deposits.
Shelter belt/trees	Row or stand of mature trees.

APPENDIX 2: INTERPRETED MATERIALS LAYER DESCRIPTION

Fields	
type	Material type e.g. "rock at/near surface"

Type	Appearance
Rock at/near surface	Areas of exposed volcanic rock. Blocky-textured and high-contrast on photographs, typically with intricate shadows; block sizes are highly variable and are generally dictated by joint spacing (usually > 1-2 m). Rock generally has a high albedo, possibly due to weathering/lichen growth (fresh volcanic rock is dark). Typically forms steep cliffs, but can also crop out on gentle slopes. In some locations rock is thinly mantled by colluvium and/or loess.
Talus	Boulders of loose rock, mainly at bases of steep cliffs. These deposits lack the large (> c. 2 m), coherent masses of intact bedrock. High-contrast on photos. Talus is differentiated from colluvium mainly by its coarser texture, steeper slope, and position at/near the bases of rock bluffs.
Colluvium	Remobilised silt (loess) and gravel to boulder sized rock clasts. Mainly fine textured and quite smooth surface; typically well vegetated. Mainly in gullies, but may also occur on moderate slopes below exposed rock, talus or loess. Collected in gullies and major rills between loess aprons. Material underlying debris fans and landslide deposits (see below) is mapped as colluvium.
Loess	Silt and fine sand, commonly weathering to stiff clay. On steeper slopes, thick deposits of loess are typically rilled where tunnel-gully erosion has developed. This is manifest as shallow sub-parallel gullies; if the erosion is deep enough, "bad-lands" topography may form. In farmed areas, terracettes may also develop where stock have repeatedly walked, forming narrow steps and short risers, particularly on steeper faces. It can also form featureless mantling deposits, especially on ridge crests where there is little drainage catchment or run-off.
Alluvium	Featureless flat ground, typically with a nearby stream occupying the valley floor. Deposits range from gravel to silt and peat. In coastal areas flat ground merges imperceptibly with the shorefront (mostly sand).
Sand & gravel	Flat coastal ground is interpreted as beach deposits composed of sand and gravel. Low arcuate hills near the coast are sand dunes and/or relict beach ridges.
Boulders	Boulder beds commonly form narrow strips of beach below coastal bluffs, and are likely to be talus deposits reworked by wave action.
Fill	Large-scale industrial works (quarries, roading and tunnel infrastructure, Lyttelton Port) are obvious as flat and/or battered ground. Smaller areas underlie houses, water storage tanks, dams and playing fields/parks. Man-made fill typically consists of a range of clast sizes from boulders to gravel.
Unknown	Some areas that are forested, beneath cloud cover on certain images, or steep topography that cannot be determined from topographic models (LiDAR), are mapped as unknown.

APPENDIX 3: GENESIS LAYER DESCRIPTION

Fields	
type	Genesis or process type, *e.g. "Rockfall (recent)"*

Type	Appearance
Rockfall (recent)	Generally high concentration of boulders in run-out zone; fresh (unweathered) rock scar evident in source area; typically appears brown-orange due to intermixed soil; some boulder trails visible as flattened vegetation or pock-marks; most recent rockfalls in the Port Hills were from the 22^{nd} February 2011 aftershock and are not present on 4^{th} September 2010 GeoEye satellite image.
Rockfall (many scattered boulders)	Local piles of talus and high concentrations (1 every 2-10 m) of boulders; primarily below rock cliffs.
Rockfall (few scattered boulders)	Low concentration (1 every 10-50 m) of scattered boulders.
Dune	Dunes composed of sand form a low-amplitude (1-2 m high), 100-150 m wide subdued, curved strip across the valley, generally sub-parallel to the modern coast. There is usually a gap where the local stream has cut through.
Beach	Narrow strip of sand and gravel (in sheltered areas) to boulders (usually below coastal cliffs). May include some estuarine and alluvial deposits. Some beach ridges apparent as low arcuate hills similar to dunes.
Rills / terracettes	Multiple shallow gullies (rills) and small steps/stock tracks (terracettes). Deeper rilling forms bad-lands erosion canyons.
Fans	Typically rounded or conical lobes at the bases of narrow (side) valleys composed of remobilised silt (loess) and rock (colluvium and debris flow deposits); source usually obvious with colluvium in catchment. Surface texture can be hummocky, but more often smooth; gentler slope than colluvium or loess-covered slopes.
Landslide scar	Includes landslide source area and debris. Steep, hummocky ground, commonly with ponds and localised areas of poor drainage. Run-out area (debris train) may merge with colluvium/debris fan (possibly from secondary debris flows off the toe). Deposits typically consist of shattered mixtures of cobbles and boulders to clay and silt sized clasts. Usually initiated in loess or colluvium, occasionally rock. Categorised into: Recent: head scarp usually distinguishable from debris. Scarp area mapped as underlying material, debris mapped as colluvium. Relict: hummocky ground, but may be blanketed with loess (older) and head scarp degraded/eroded; mapped as colluvium.
Swamp/wetland	Flat, waterlogged ground, usually underlain by peat, with minor alluvial gravels and silt. Swamps commonly have a lower albedo than surrounding areas, and typically richer vegetation.