The January 2013 Mt Haast Rock Avalanche and Ball Ridge Rock Fall in Aoraki/Mt Cook National Park, New Zealand

G T Hancox, R Thomson

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G.T. Hancox, GNS Science, PO Box 30368, Lower Hutt
R. Thomson, 11 Leitrum Street, Cromwell

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ABSTRACT

Two significant landslides occurred in the Aoraki/Mt Cook National Park of New Zealand's Southern Alps in January 2013. The first was a large rock fall on Ball Ridge which occurred during the 9-10 January rainstorm. This was followed on 21 January by much larger rock avalanche from a nearby peak 5 km northeast of Mt Cook. The rock avalanche from the ridge between Mt Haast and Mt Dixon at 2:09 pm on 21 January 2013 originated in very weak rock, associated with a fault zone developed sub-parallel to bedding in the greywacke bedrock. The avalanche was initiated by a collapse of the ridge crest at an elevation of about 3040 m with an estimated volume of up to ~1 million m^3. The falling rock debris entrained snow and ice as it flowed down the névé south of Mt Haast with an average velocity of up to 160 km per hour. Although the rock avalanche occurred during fine weather without an obvious trigger, heavy rainfall (>900 mm) during two rainstorms in early January is believed to have strongly influenced the time of the failure.

The rock avalanche ran out 2.9 km on to the Grand Plateau and came to rest about 200 m west of Plateau Hut near the top of the Hochstetter Icefall at an elevation of ~2100 m. The avalanche debris (boulders, gravel, and sand up to 5 m thick) covers an area of about 0.8 km^2 on the Grand Plateau, with an estimated total volume of ~2 million m^3, of which about half is snow and ice. The shaking caused by the rock avalanche was recorded on several GeoNet seismographs at distances of 29–139 km from the source, and is calculated to have had an average local magnitude of M_L 2.25.

This recent collapse appears to have reduced the risk of future large failures from the ridge between Mt Haast and Mt Dixon because of the reduced source area. Repeat failures of similar size to the recent collapse are unlikely, but minor retrogressive rock falls should be expected in the future. There are several sites where small rock falls could occur in the future, such as the overhanging headscarp on the western side, and the areas of loose debris on the upper failure zone. The annual risk (loss of life) at Plateau Hut from future rock avalanches from the source area on Mt Haast is estimated to be very low ($\sim10^{-7}$).

The ~150,000 m^3 rock fall on the popular Ball Ridge tramping track to Ball Pass occurred in an area of weak, argillite-dominated rock during the 9-10 January 2013 rainstorm when ~383 mm rain was recorded at Mt Cook. Although the rock fall was triggered by rainfall, the slope was made more susceptible to failure by erosion and glacial retreat over the last 100 years. The rock fall area on the northwest side of the ridge is expected to increase in size over time, but is not expected to prevent use of the Ball Ridge track if further large collapses occur, although the route may become more difficult to use.

The Ball Ridge rock fall and Mt Haast rock avalanche in January 2013 are the most recent large rock slope failures in the Southern Alps, providing further evidence of increased slope instability in the last 50 years. Given the marked climatic and physiographic changes that have occurred, large slope failures in alpine areas are expected to continue in the future, particularly during rainstorms and strong earthquake shaking (≥MM8). The next Alpine Fault earthquake is expected to trigger numerous large rock falls, rock avalanches, and other types of landslides in the Southern Alps.

KEYWORDS

Mt Haast rock avalanche, Ball Ridge rock fall, January 2013, Aoraki/Mt Cook National Park, Southern Alps, New Zealand, Alpine Fault earthquake.

1. INTRODUCTION

Shortly after 2 pm on Monday 21 January 2013 a large rock avalanche occurred on the ridge between Mt Haast and Mt Dixon, about 5 km northeast of Mt Cook, in Aoraki/Mt Cook National Park (Area A, Figure 1). A large volume of very weak greywacke sandstone and argillite on the ridge between Mt Haast and Mt Dixon collapsed without warning or apparent trigger on to the snowfield below. The sliding mass of rock debris, which included angular rock fragments and large blocks several meters across, entrained up large volumes snow and ice as it flowed rapidly out on to the northern end of the Grand Plateau snowfield, with a vertical fall of about 900 m and a total travel distance of about 3 km. The north eastern lobe of debris came to rest about 200 m from Plateau Hut, the main base for climbs of Mt Cook and other peaks in the area (Figures 2 and 3). The Mt Haast rock avalanche was the largest landslide to have occurred in the region since the ~10-15 million m^3 rock avalanche from the summit of Mt Cook in December 1991.

The Mt Haast rock avalanche was the second major landslide in the Aoraki/Mt Cook area in January 2013, occurring less than 2 weeks after a large rock fall from Ball Ridge, 9 km south of Mt Haast (Area B, Figure 1). The latter failure apparently occurred during a rainstorm on 9-10 January 2013, during which 367 mm of rain was recorded at Mt Cook Village. The Mt Haast rock avalanche was important because it illustrated the potential hazard that rock avalanches present to climbers and users of alpine huts in the Southern Alps of New Zealand. Following the initial rock avalanche concerns had been raised in the news media regarding the risk to Plateau Hut from further rock avalanches and/or rock falls from the source area on the Haast-Dixon ridge. GNS Science initiated a landslide response under the GeoNet Project to inspect and assess both of these slope failure areas, and to assess the hazard and risk a future Mt Haast rock avalanche presented to Plateau Hut, which had been closed by the Department of Conservation (DOC) as an interim measure until the risk to the hut could be assessed. Inspection of the upper Ball Ridge rock fall area close to a popular tramping track (Area B, Figure 1) was a secondary objective for the landslide response.

The response to the Mt Haast rock avalanche was initiated by Graham Hancox (GeoNet Landslide Coordinator) on 22 January 2013. Royden Thomson, an engineering geologist based in Cromwell was engaged by GNS Science to carry out a helicopter inspection of rock avalanche in association with Aoraki/Mt Cook DOC staff (Jim Spencer, Senior Ranger) that afternoon, and assess the risk to Plateau Hut to determine whether or not the hut should be reopened for public use. On the basis of field observations and a geological hazard model, provisional advice was given to DOC on site by Royden Thomson about the rock avalanche and safety of Plateau Hut. Similar comments as appropriate were conveyed to the news media at Mt Cook later that afternoon.

This report describes and illustrates the extent and features of the 21 January 2013 Mt Haast rock avalanche (Area A), and the Ball Ridge rock fall of 9 January 2013 (Area B), both of which are shown in Figure 1. The report incorporates notes, aerial photos, maps, and cross sections included in an Immediate File Report by Royden Thomson dated 7 February 2013. The risk to Plateau Hut from similar geological hazards was recently reassessed in a separate report for DOC (Hancox and Thomson, 2013). The results of that assessment have been included in this report with the approval of the Department of Conservation.

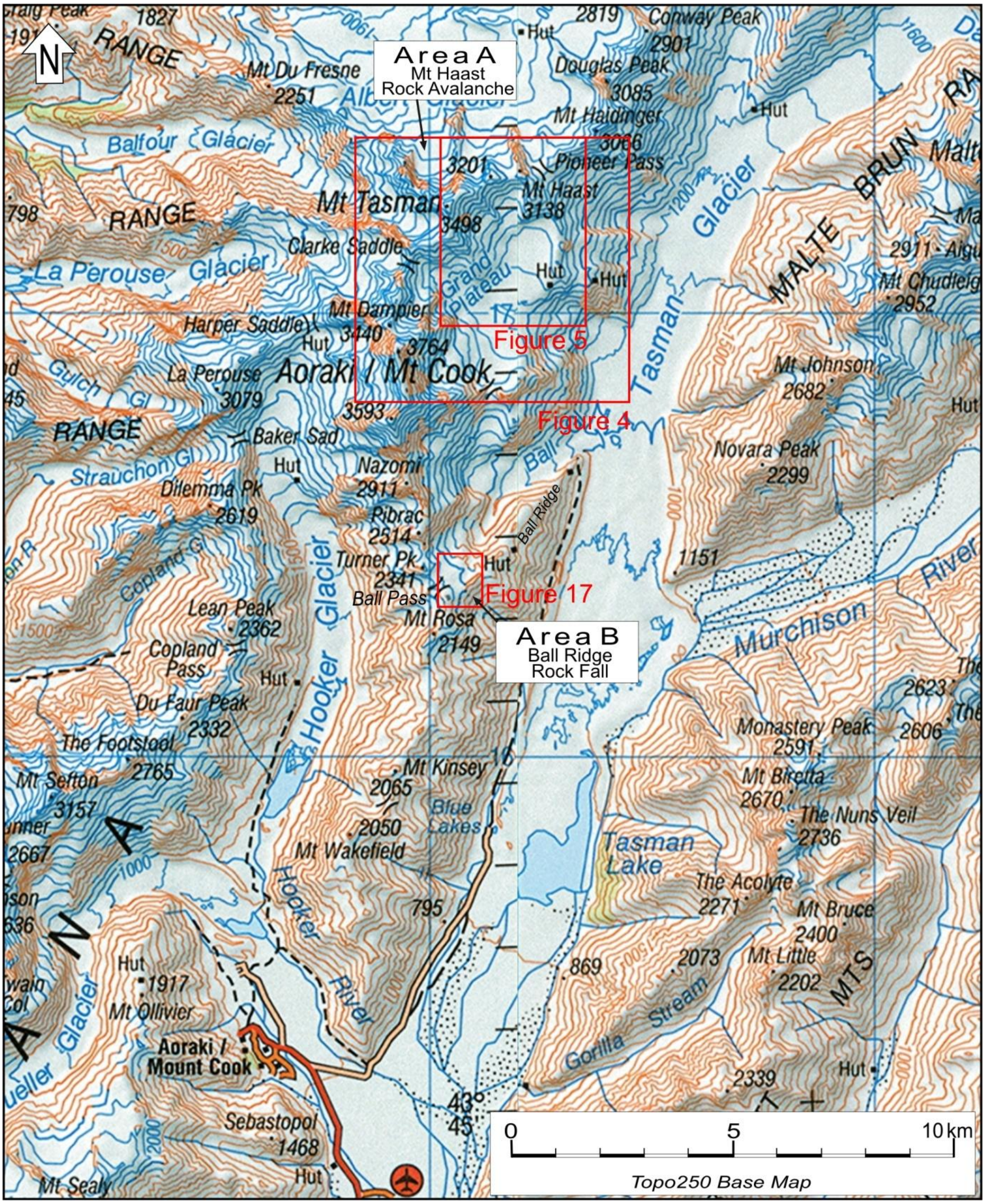

Figure 1 Map showing the location of the 21 January 2013 Mt Haast rock avalanche area (Area A) and the 9 January 2013 Ball Ridge rock fall area (Area B) in Aoraki/Mt Cook National Park.

2. MT HAAST ROCK AVALANCHE

2.1 TIME AND LOCATION

The rock avalanche on the southwest side of the ridge between Mt Haast and Mt Dixon on the afternoon of 21 January 2013 was witnessed by climbers at Plateau Hut and on peaks in the vicinity of Mt Cook. A photo taken by climber Anna Seybold on Mt Dixon which shows the rock avalanche running out across the Grand Plateau (Figure 2) indicates that the failure occurred at about 2:09.17 pm. A video *(http://www.youtube.com/watch?v=E28_3uj9K0g)* of the rock avalanche taken by Neil Wiltshire, a climber at Plateau Hut when the rock avalanche occurred, indicates that the frontal part of the avalanche flow had an average velocity of up to ~150 km/hour as it surged 1.5 km across the plateau towards the hut.

Figure 2 This photo of the highly turbulent frontal part of the Mt Haast rock avalanche running out across the Grand Plateau, with Mt Cook visible in the distance, was taken at 2:09 pm on 21 January 2013. A small rock fall (*rf*) in the foreground, which enlarged several days later, is one of three thought to have been caused by shaking associated with the rock avalanche (*Photo by Anna Seybold, 21 January 2013*).

The location and extent of the Mt Haast rock avalanche is visible on a NASA EO-I ALI satellite image of the Mt Cook area taken on 13 February 2013 (Figure 3), which clearly shows the source area, flow path and accumulation zone of the avalanche, which travelled ~3 km from the failure source and down the Grand Plateau to within 250 m of Plateau Hut. The terrain in the rock avalanche source area and flow path is shown by the topographic map in Figure 4, which also illustrates, for comparison, the extent and flow path of the much larger (~10-14 Mm^3) 1991 Mt Cook Rock avalanche (Hancox et al 1991, Mc Saveney 2002). Figure 5 is a more detailed map of the Mt Haast rock avalanche source area and flow path. A long section slope profile (Figure 6) shows the vertical fall, runout length, and slope angles down the flow path of the rock avalanche. A photo taken from the summit ridge of Mt Cook clearly shows the source area and full extent of the failure on the Grand Plateau (Figure 7).

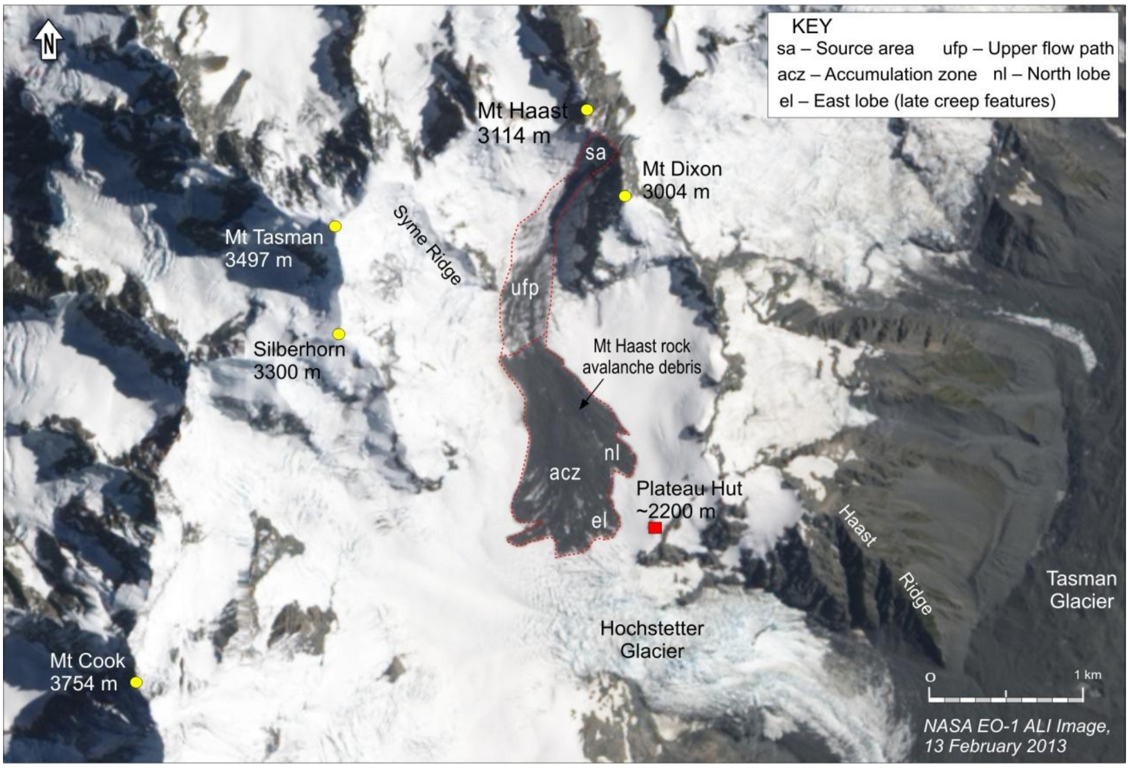

Figure 3 NASA EO-I ALI satellite image of the Mt Haast rock avalanche area taken on 13 February 2013 showing the source area *(sa)*, the upper avalanche flow path *(ufp)*, accumulation zone *(acz)*, and the distal lobes *(nl, el)* of the rock avalanche debris, which travelled to within ~200 m of Plateau Hut.

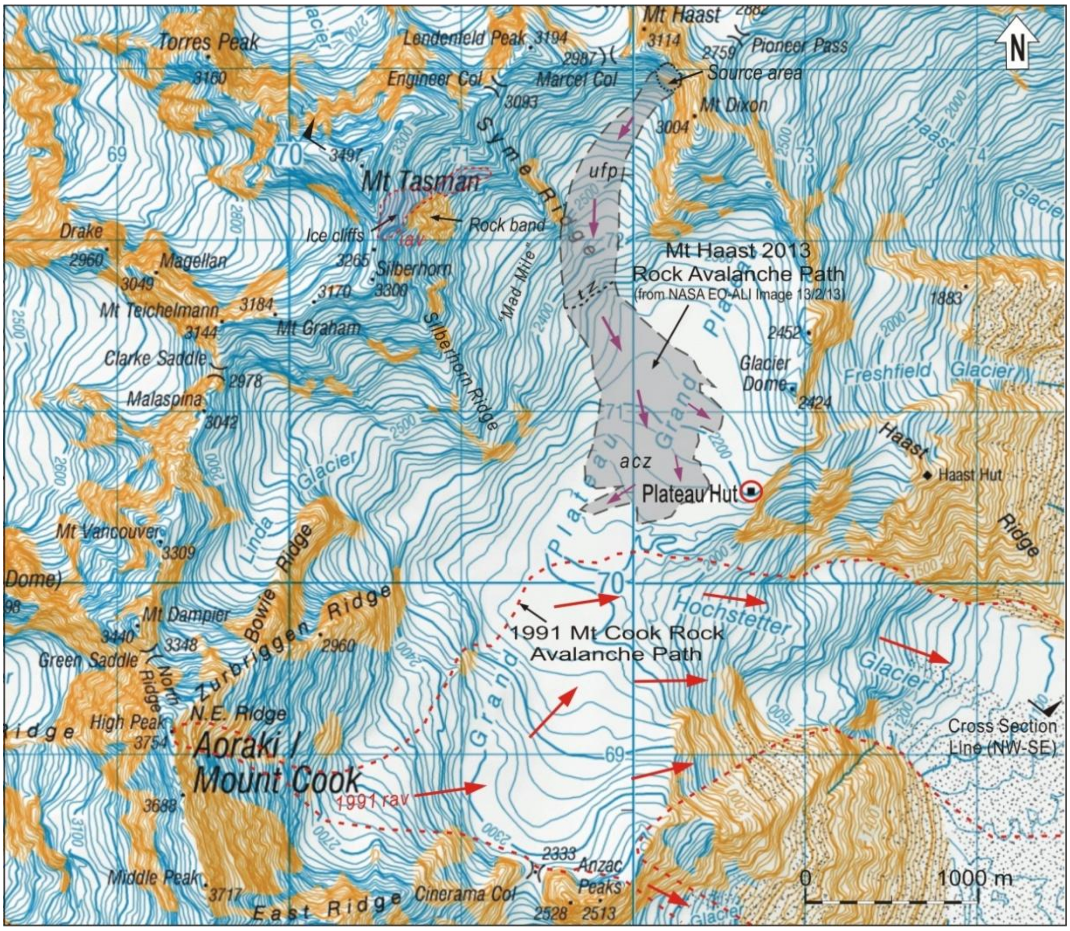

Figure 4 Topographic map of the 2013 Mt Haast rock avalanche path (source area, upper flow path (*ufp*), transition zone (*tz*), and accumulation zone (*acz*) taken from NASA Satellite Image of 13/2/13), and the 1991 Mt Cook rock avalanche path (*Base Map Topo50BX16*).

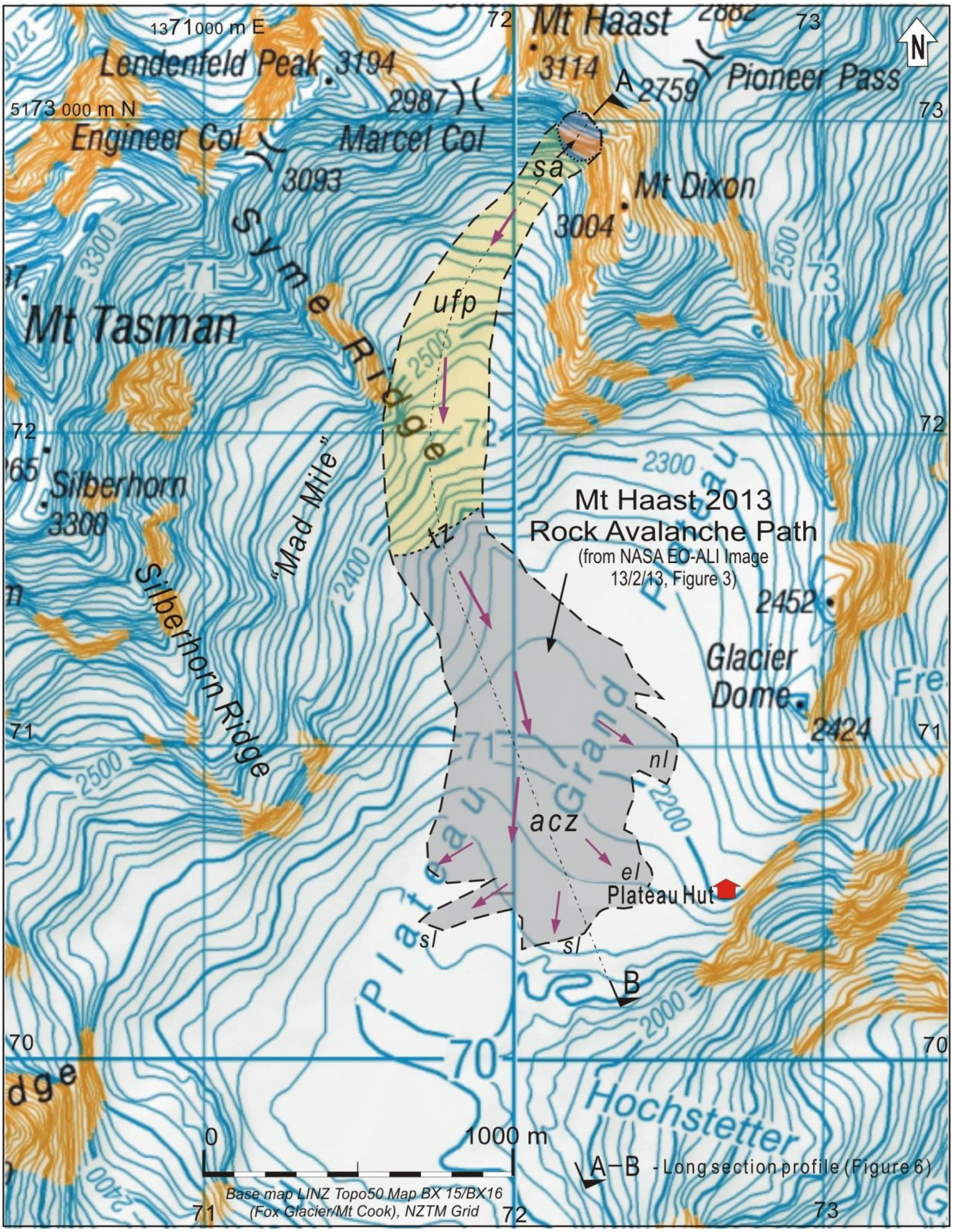

Figure 5 Topographic map showing the extent (from NASA Satellite image) and main features of the 2013 Mt Haast rock avalanche, including the source area *(sa)*, upper flow path *(ufp)*, transition zone (tz), the debris accumulation zone *(acz, which covers an area of ~0.80 km^2)*, and the northern *(nl),* eastern *(el),* and southern *(sl)* distal lobes of debris which travelled to within ~200 m from Plateau Hut. Video of the event shows that these lobes formed during the final creeping stages of the avalanche.

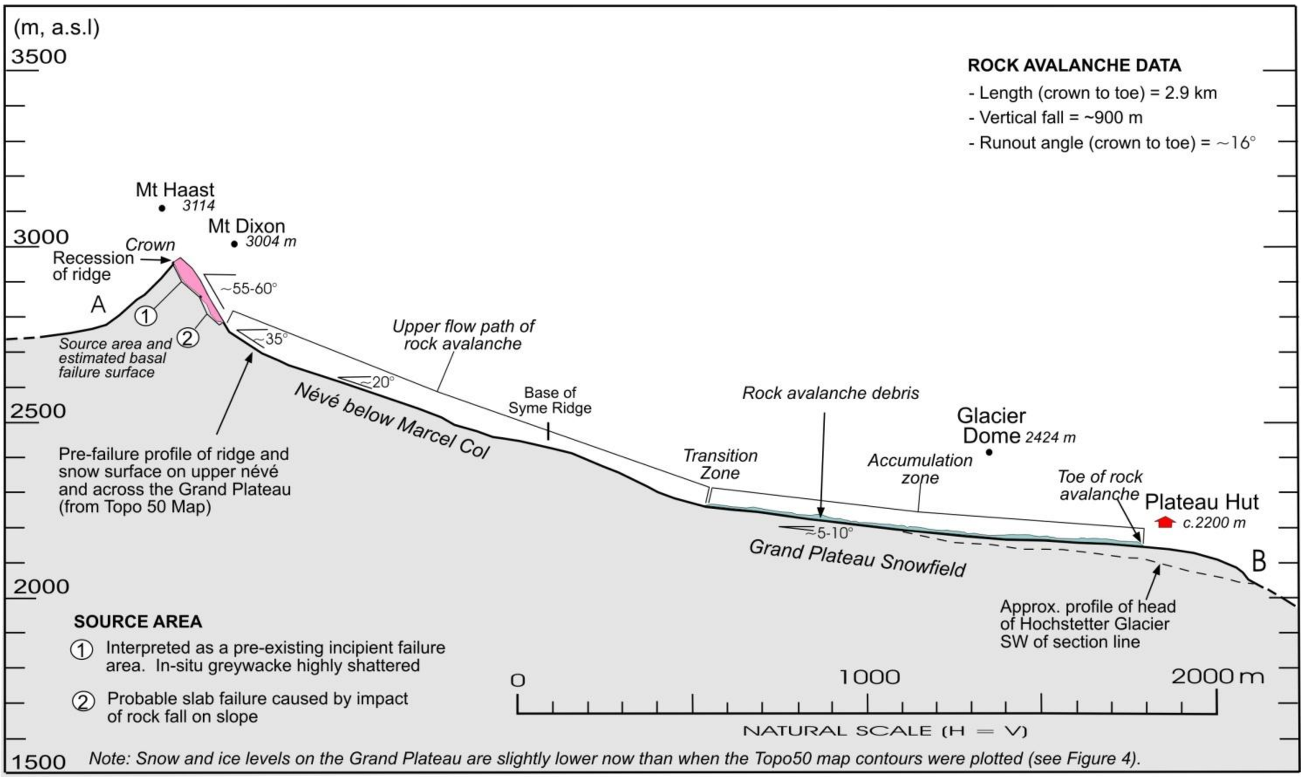

Figure 6 Long section down the rock avalanche showing the source area on the Haast–Dixon ridge, slope angles down the flow path and accumulation zone, and the 2.9 km runout length. The section line location is shown on Figure 5.

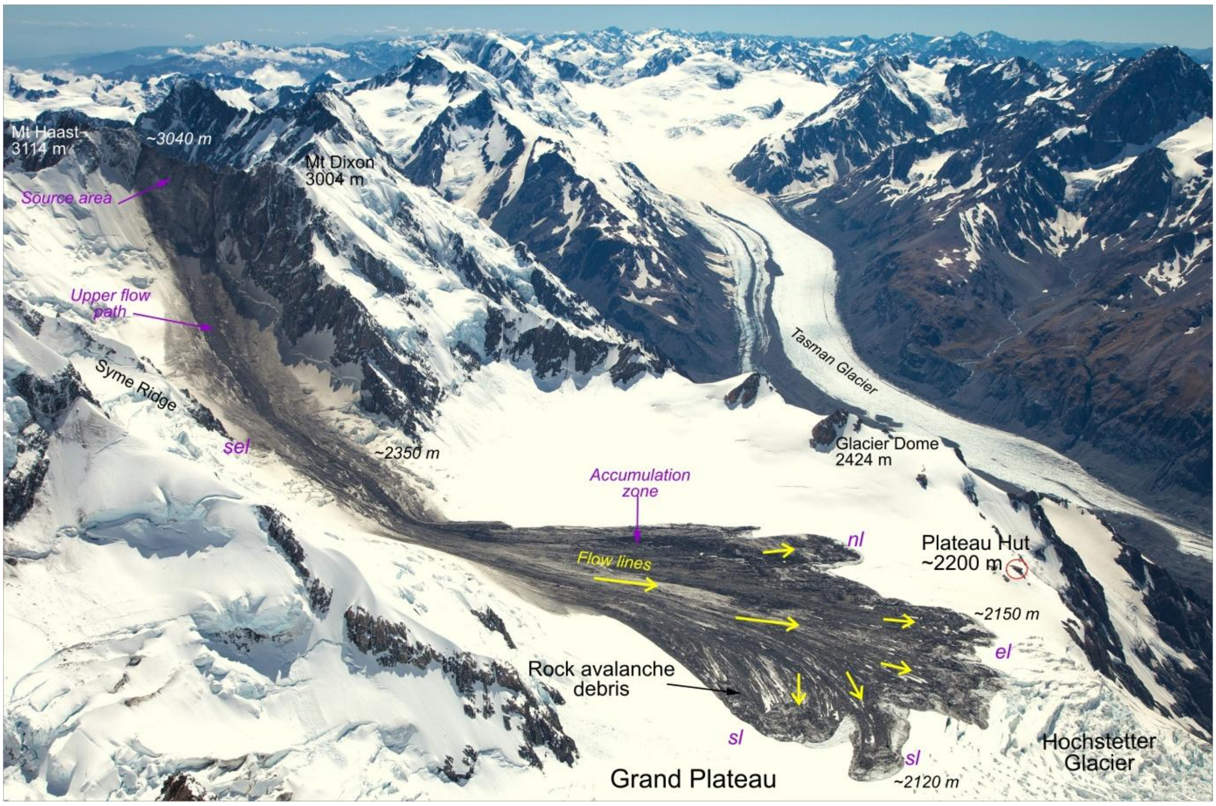

Figure 7 Photo taken from the summit ridge of Mt Cook showing the location, extent, and main features of the 21 January 2013 Mt Haast rock avalanche (see Figure 5 for details). There was marked super-elevation on the southwest side of the upper flow path where debris passed over the base of Syme Ridge *(sel)* before discharging onto the Grand Plateau *(Photo by Mark Watson, 22 January 2013)*.

2.2 DESCRIPTION OF THE ROCK AVALANCHE

2.2.1 Source area

2.2.1.1 Physiography

The headwall bordering the northern part of the Grand Plateau is very steep to precipitous (Figure 5). A long section through the failure site (Figure 6) indicates the pre-failure ridge was asymmetric, being somewhat less steep (45°) on the north-east side, with a uniform slope of up to 60° on the southwest side of the ridge between Mt Haast and Mt Dixon. In profile the pre-failure ridge crest was somewhat irregular. The ridge and the area of rock that collapsed, a distinct bulge on the southwest side of the ridge between Mt Haast and Mt Dixon, is shown approximately on a photo taken from the summit of Mt Cook in 1968 (Figure 8).

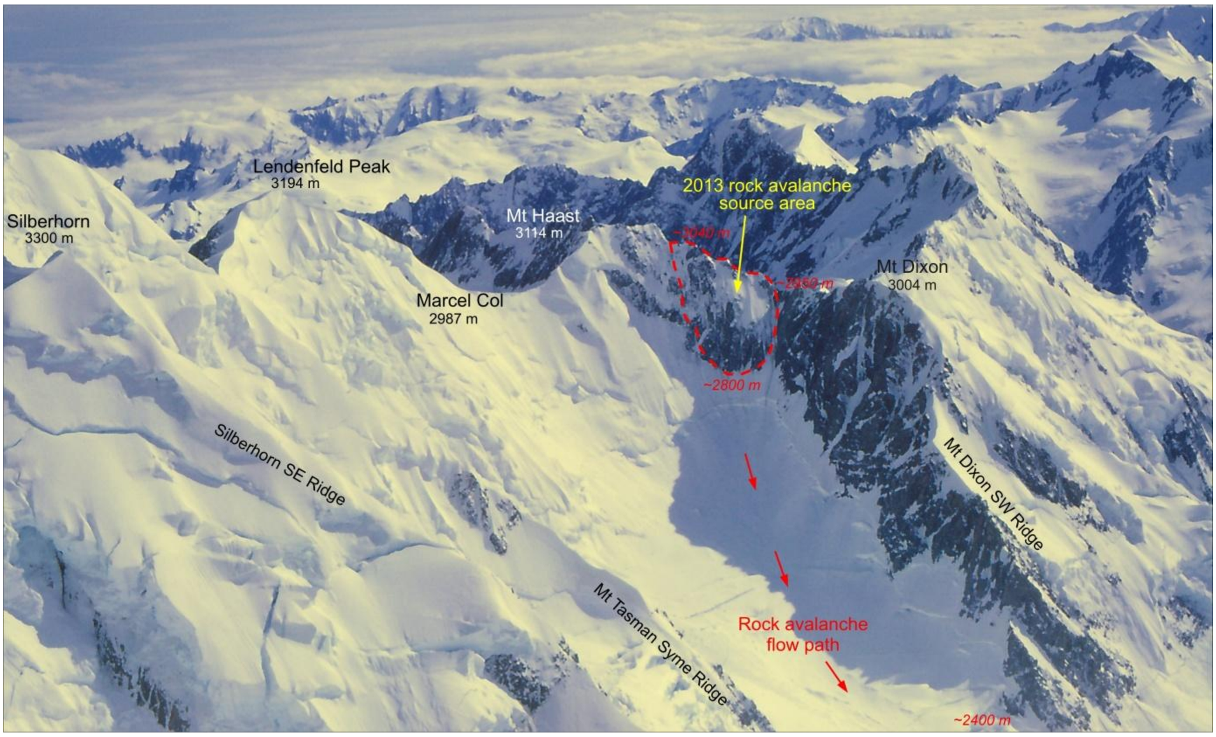

Figure 8 View of the 2013 rock avalanche area in 1968 showing the location and extent of the source area. *(Photo by G. Hancox, January 1968)*

Following the collapse on 21 January 2013 failure, it is apparent that the ridge crest in the source area is now aligned more in a northeast direction, and ridge elevation in that area is now considerably lower, possibly by about 25 m. However, as shown in Figure 9, the ridge crest remains irregular, but with a different profile. The ridge crest is sharp and steep, but slope angles flatten quickly to the southwest, and there is little gradient change, or face regression, near the base of the failure (Figure 6).

2.2.1.2 Geology of the source area

(a) <u>*Rock types*</u>: The bedrock in the rock avalanche source area is 'greywacke', which comprises both hard (indurated) grey sandstone, and fissile, and more thinly-bedded dark grey argillite (mudstone/siltstone). Both of these lithologies are present in the source area, and each was sampled from within the avalanche debris (by Jim Spencer, 22 January). Areas of whitish material visible in shadow at the western end of the failure area (Figures 9 and 10) are likely to be chert or a similar siliceous lithology.

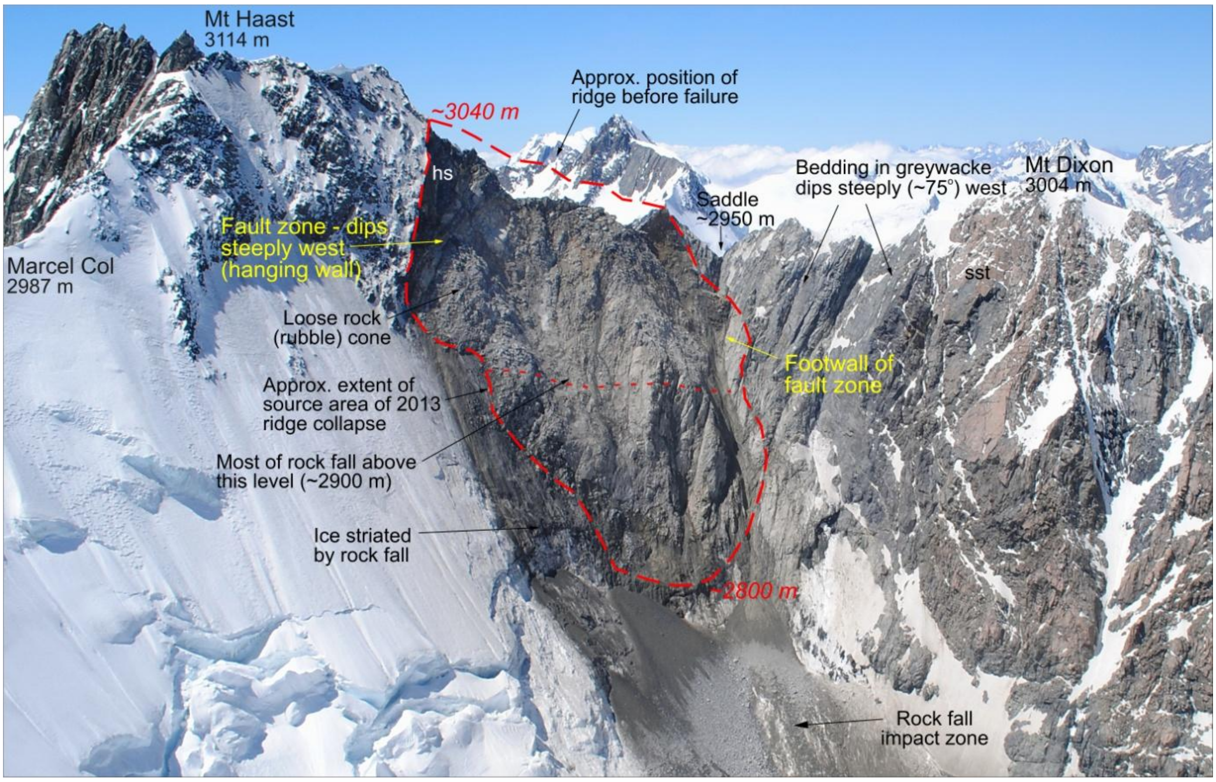

Figure 9 Aerial view of the source of the 2013 rock avalanche. The failure occurred in very weak rock associated with a steeply dipping fault, formed sub-parallel to bedding, which dips steeply (~75°) to the west. The failure, mainly from above the ~2900 m level, lowered the ridge about 25 m, leaving a very steep to overhanging western headscarp *(hs)* from which further (smaller) failures are expected. The impact zone of the initial rock fall is clearly visible on the ice slope below the source area *(Photo by R. Thomson, 22 January 2013)*.

(b) Bedding: Bedding dips to the west at about 75° within the Mt Dixon massif, but it is poorly developed and the lithology appears to be mainly sandstone (Figure 9). Steep west-dipping bedding is also present on the north flank of the failure zone and at lower parts of the failure area, where a mixture of sandstone and argillite is present (Figure 9). To the west of the failure scarp, bedding within the Mt Haast massif dips steeply (≥65°) to the west, but some minor folding is also present, as indicated by the vertical beds at lower level at the bottom/centre in Figure 11.

(c) Faulting: Several features suggest the presence of a fault trending through the failure zone. These include: (a) the slope failure has exposed a pre-existing, sub-vertical erosional 'gutter' along the eastern margin of the source area (Figure 9). This appears to be aligned on a narrow zone forming the footwall of the fault zone which strikes parallel to bedding; (b) the fault juxtaposes the more massive sandstone units exposed on Mt Dixon, with the thinner, sandstone/argillite beds outcropping to the west. While the fault is locally slightly steeper than bedding, it is classed as a bedding fault; and (c) the greywacke bedrock is generally intensely shattered over a distance of about 150 m in a westerly direction from the ~2950 m saddle on the Haast–Dixon ridge (Figure 10).

On this basis, it is postulated that there is a zone of strong tectonic shearing that extends across to the tentative-identified hanging wall (Figure 10). Further to the west, the Mt Haast ridge is also highly fractured, with discontinuities dipping steeply to the east. The fault zone exposed in the Dixon-Haast ridge is thought to be the northeast-striking fault shown in about that location on the 1:250,000 (Aoraki) geological map (Cox and Barrell, 2007). The weak rock on the Dixon-Haast ridge is well known in climbing circles, and is referred to in the Aoraki Mt Cook guide for mountaineers as a *'rotten rock ridge'* (Palman, 2001).

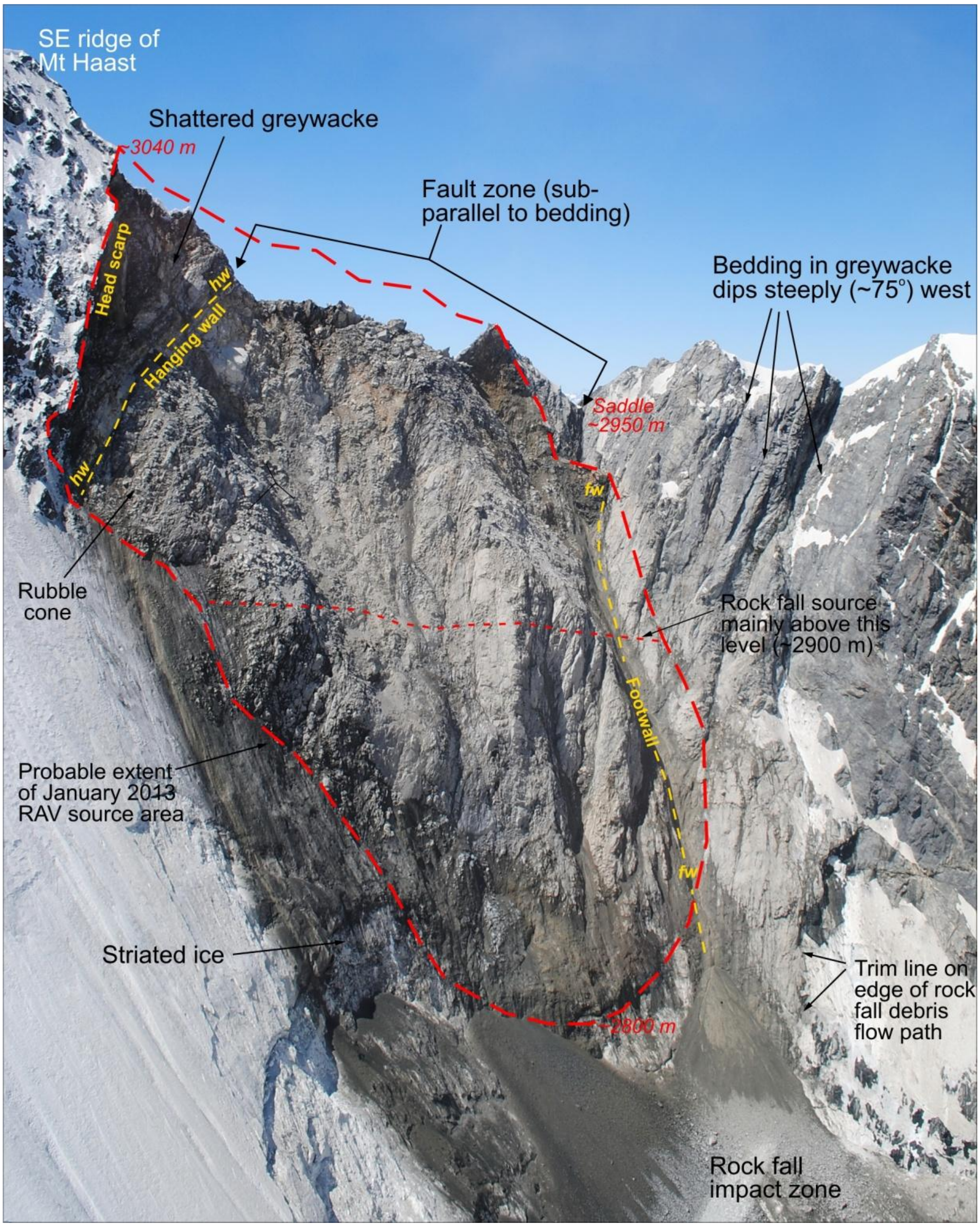

Figure 10 Closer view of the 2013 rock avalanche source area showing the footwall and hanging wall of the fault zone, the rock fall impact zone, and other features discussed above. *(Photo by R. Thomson, 22 Jan 2013)*

2.2.1.3 Extent and features of the source area

As shown in Figures 9 and 10 the source area of the rock fall that initiated the rock avalanche extended from about 3040 m to 2800 m. The bulk of the rock fall debris was derived from the upper ~140 m of the failure zone above the ~2900 m level, with relatively little material shed from the lower 100 m. The ridge crest appears to have been lowered by about 25 m and moved several metres to the northeast (Figure 6).

Coarse rock debris remains on the upper face within the failure zone, including the slope below the overhanging headscarp on the southeast ridge Mt Haast. The rubble appears to have been translated many metres from its original position during the failure, and reflects the very poor rock mass condition visible in the source area (Figure 9 and 10).

At approximately RL 2870 m there is a change from brecciated to intensely shattered rock. Most of the failure appeared to involve mainly ’in-situ’ breccia formed by earlier progressive slow gravitational movements of the upper 200 m of the slope on the southwest side of the Dixon–Haast ridge northwest of the ~2950 m saddle. The east side of the failure area is clearly defined by the footwall of the fault zone, while on the west side the rock mass above the headscarp appears to be in-situ greywacke, but is intensely fractured (Figures 9 and 10).

Effects of the 2013 rock avalanche were also observed on the northeast side of ridge between Mt Dixon and Mt Haast, where two small to moderate-size rock falls are evident (Figure 11). Both of these rock falls are believed to be secondary failures that were triggered by shaking caused by the initial rock fall and passage of the rock avalanche as it flowed out of the névé below the south face of Mt Haast and across the Grand Plateau (Figure 7).

Figure 11 Aerial view of the Mt Dixon–Mt Haast ridge from the northeast showing the position of the 2013 failure on the opposite side of the ridge, the footwall *(fw)* and hanging wall *(hw)* of the fault zone, and the source areas *(SA)* of recent rock falls which are attributed to shaking associated with the rock avalanche. *(Photo by R. Thomson, 22 Jan 2013)*

2.2.2 Features of the rock avalanche debris flow

The extent and main features of the Mt Haast rock avalanche flow path are shown in Figures 5 and 7, while Figure 2 shows the debris flow surging across the Grand Plateau. The shaking associated with the rock avalanche was recorded on several GeoNet seismograph stations in the South Island, including those at Fox Glacier, Inchbonnie, and Jacksons Bay (Figure 12). Using the seismograph records from Fox Glacier, Rata Peaks, Jackson Bay, and Inchbonnie an equivalent average local magnitude of M_L 2.25 has been calculated for the shaking caused by the avalanche (pers. comm. Brian Ferris).

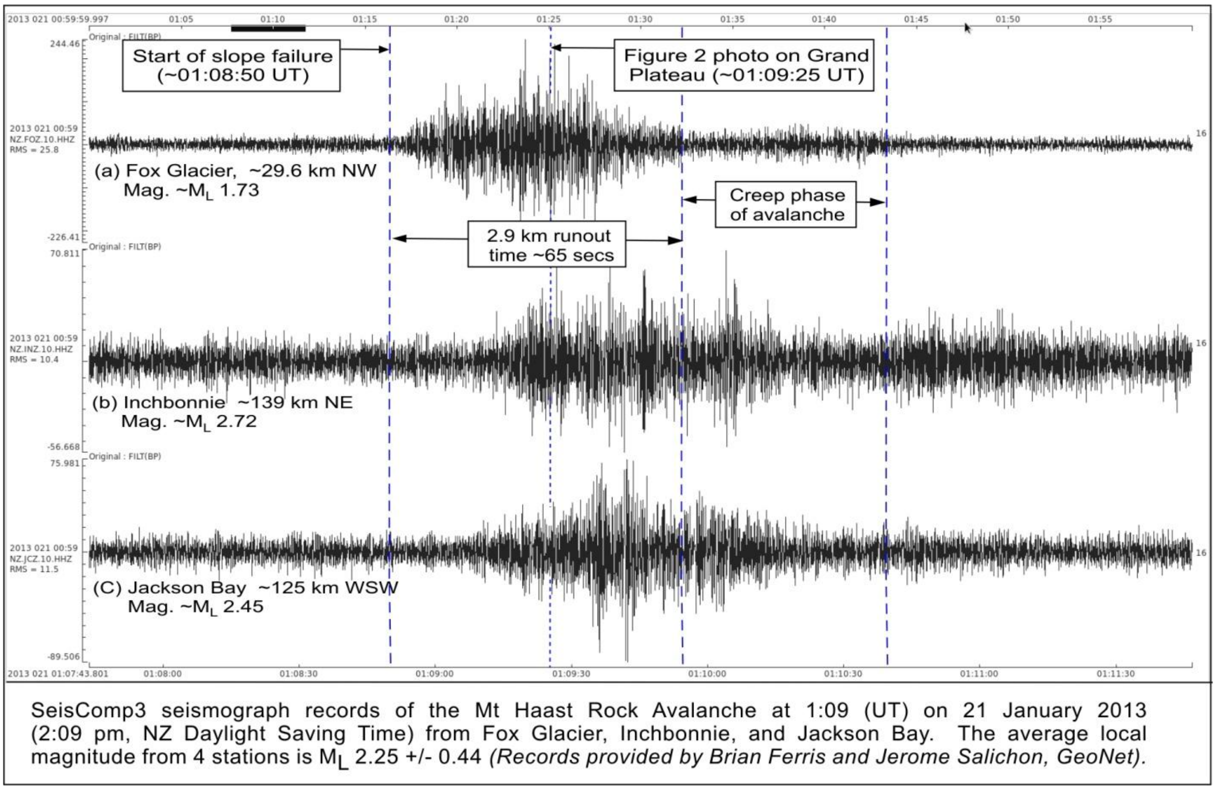

Figure 12 Seismograph records of the Mt Haast rock avalanche from Fox Glacier, Inchbonnie, and Jackson Bay from ~01:08:50–01:10:45 UT on 21 January 2013. An average local magnitude of M_L 2.25 has been calculated from seismograph records from Fox Glacier, Rata Peaks, Jackson Bay, and Inchbonnie. The 65 second travel time for the 2.9 km runout of the avalanche indicates an average velocity of up to ~160 km/hour.

The seismograph records suggest that the travel time for most of the 2.9 km runout of the rock avalanche was approximately 65 seconds, indicating an average velocity of 160 km per hour (Figure 12). This is similar to the velocity (up to 150 km/hour) indicated by live video of the final stages of the debris flow as it travelled across the Grand Plateau towards Plateau Hut. The video footage indicates that the distal lobes of debris formed during the final creep phase of the avalanche, during which piles of boulders, gravel, and entrained snow and ice in the avalanche toe area slid slowly across the snow surface (Figures 13 and 14).

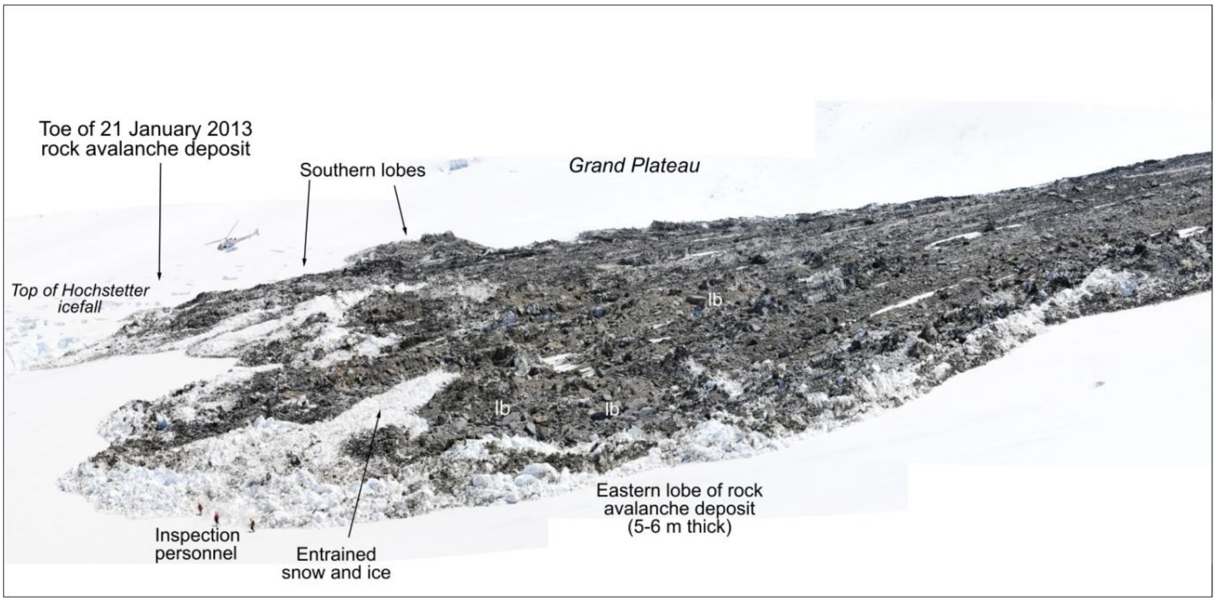

Figure 13 The toe of the Mt Haast rock avalanche deposits up to 5-6 m thick includes large boulders *(lb)* and gravel with entrained snow and ice. The three figures (lower left) and the helicopter (centre left) provide a scale for the deposit. *(Photo by R. Thomson, 22 Jan 2013)*

Figure 14 Close up views of the rock avalanche debris in the toe area showing (a) the deposits of angular gravel and boulders with Mt Cook in the distance, and (b) distinctive gravel trails (*gt)* and flow lines *(fl)* which were formed as the mounds of gravel and boulders slid slowly forward on the firm snow surface. The figures in both photos indicate the scale of the deposits *(Photos by Mark Watson, 22 January 2013)*

2.2.3 Size and features of the rock avalanche

2.2.3.1 Size of the initial slope failure

As shown in Figures 9 and 10 the source area of the rock avalanche comprised mainly the upper ~140 m of the ridge, with relatively little material from the lower part of the source area, where material seems to have been removed by a much earlier slope failure to form the very steep slopes below the ridge that are visible in the 1968 photo (Figure 8).

Based on approximate dimensions scaled from the topographic map (Figure 5) the size of the initial slope failure from the source area is estimated to be as follows:

(a) Upper section:	Width	~200–250 m
	Height	~120–140 m
	Mean thickness	~20–25 m
	Estimated Volume	~480,000–875,000 m^3
(b) Lower section:	Width	~150 m
	Height	~100 m
	Mean thickness	~5-7 m
	Estimated Volume	~75,000–105,000 m^3
(c) Total volume:		~575,000–980,000 m^3

Given the uncertainty of these dimensions, we believe that as a realistic estimate the volume of the rock mass that collapsed and initiated the rock avalanche was up to approximately 1 million m^3.

2.2.3.2 Upper flow path and transition zone

Photos taken after the rock avalanche show that the initial rock slope collapse created a distinct 'impact zone' which was largely devoid of rock debris on the ice below the source area (Figures 9 and 10). The disintegrating rock mass appears to have moved very quickly downslope as a rock avalanche and entrained considerable volumes of snow and ice from the steep slopes below the source area. The avalanche flowed rapidly in a southerly direction down the snow névé south of Mt Haast and surged out across the northern end of the Grand Plateau (Figure 5).

The velocity of the rock avalanche is thought to have been very high, probably at least 150-160 km/hour, as indicated by the video evidence of its passage across the Grand Plateau, the seismograph records discussed earlier (Figure 12) and the marked super-elevation of the avalanche flow where debris passed over the base of Syme Ridge (Figure 7). Apart from fine gravel and grey silt and sand, little rock debris was deposited along the upper flow path. At the transition zone the character of the rock avalanche changed from mainly flow to deposition (accumulation), about 1.4 km from the toe of the deposit (Figures 5 and 7).

2.2.3.3 Accumulation zone

The multi-lobed accumulation zone of the rock avalanche deposit extends over a significant area of the Grand Plateau west and north of Plateau Hut (Figures 3, 5, and 7). Within this zone the total area of the rock avalanche deposit is about 800,000 m^2 or 0.8 km^2. The rock avalanche deposit, which comprises coarse gravel, boulders, and entrained snow and ice, has a maximum thickness of about 5 m near the edge of the debris, but locally is only 0.5 m thick or less, and in places the underlying snow surface is exposed (Figures 13 and 14).

Based on an assumed average debris thickness of 2.5 m, the total volume of the rock avalanche deposit is estimated to be approximately 2 million m^3, which suggests that at least half the rock avalanche deposit volume is ice and snow. This is generally consistent with observations from other recent rock avalanches in Aoraki/Mt Cook National Park which have fallen on to snow, such as Mt Cook in 1991 (McSaveney 2002), and Mt Vampire in 2008 (Cox et. al., 2008).

The avalanche path largely followed the lowest part of the snow basin before plunging over the small ice fall that extends across the slope between the base of Syme Ridge and the southwest of Mt Dixon. The avalanche expanded as it surged out on to the northern end of the Grand Plateau. The northern, eastern, and southern distal lobes of the avalanche deposit formed during the final slow phase of the movement before finally coming to rest (Figure 7). The NASA satellite image (Figure 3) shows that the east lobe of the deposit stopped roughly 200 m west of Plateau Hut, but about 50 m lower in elevation. The northern lobe stopped on the gently rising snow surface about 400 m northwest of the hut, and at its maximum elevation is approximately 10 m above the floor of the hut (Figures 5 and 7).

The distal lobes of the debris flow incorporated significant masses of snow and ice, which would have reduced travel velocities, especially where rising ground was encountered. Striations and flow lines are prominent features in the toe area of the debris (Figure 14). These features are believed to have been formed by piles of gravel and large boulders sliding across the snow surface, which from video evidence were also responsible for formation of the distal lobes of the deposit

2.3 CAUSE OF THE ROCK AVALANCHE

The slope morphology and condition of the rock mass observed after the 21 January 2013 rock avalanche indicates that the failure was initiated on the upper slopes of the ridge, and additional material was removed from the lower slope by the passage of the falling mass. The geology of the area suggests that the pre-existing rock of the upper ridge was intensely fractured and dilated (open-jointed), and as a consequence had probably been creeping slowly downslope for some (unknown) time.

The precise of conditions and factors that initiated the rock avalanche failure process prior to the collapse could not be determined. A seismic trigger for the rock avalanche is highly unlikely as it cannot be linked to a specific causative earthquake. As discussed above a distinctive seismic trace of the avalanche was recorded on several GeoNet seismographs (Figure 12), hence any tectonic earthquake likely to have triggered the slope failure should have been observable. Very heavy rainfall fell at Mt Cook in January 2013 (Table 1) which may have contributed to the timing of the failure on Mt Haast.

Table 1. NIWA Rainfall records for 1-22 January 2013 at Aoraki/Mt Cook (*http://cliflo.niwa.co.nz*). (Mt Cook Station 18125, Lat. 43.736° S; Long. 170.096° E).

Date	Rain (mm) per 24 hours to 8 am
01/01/2013	54.2
02/01/2013	335.0
03/01/2013	131.6
04/01/2013	0.0
05/01/2013	0.0
06/01/2013	0.0
07/01/2013	0.0
08/01/2013	2.8
09/01/2013	21.0
10/01/2013	346.2
11/01/2013	36.6
12/01/2013	0.0
13/01/2013	28.6
14/01/2013	62.0
15/01/2013	6.6
16/01/2013	0.2
17/01/2013	20.0
18/01/2013	19.0
19/01/2013	0.0
20/01/2013	8.0
21/01/2013	0.0
22/01/2013	0.0

NIWA reports that in 2013 more than double the usual January rainfall was recorded in the Mt Cook area, almost all of which fell between 01/01/2013 and 20/01/2013 during two severe rainstorms (Table 1). During the 01-03 January 2013 storm NIWA recorded 520.8 mm of rain at Aoraki/Mt Cook Village (Station 18125), and 406.6 mm rain fell during the 08-11 January storm. A further 137.2 mm rain was recorded from 13-21 January 2013, over the 8 days immediately prior to the Mt Haast rock avalanche.

Based on the rainfall that occurred in early January at Mt Cook, and the fact that the Ball Ridge rock fall occurred during the 9-10 January rainstorm (as discussed Section 3), it is likely that storm rainfall contributed to the timing of the Mt Haast rock avalanche. It is clear, however, that geological conditions (fault zone and weak open-jointed rock), steep glaciated topography, and ongoing gravitational stresses created the conditions that made the ridge susceptible to collapse. Saturation of the open-jointed rock mass during the January 2013 rainstorms was followed by freezing and ice wedging as rain turned to snow after the southerly change towards the end of the storm (M. Watson, pers. comm.). This indicates that although rain did not trigger the Mt Haast rock avalanche 21 January 2013, very heavy rainfall earlier in the month was the factor most likely to have influenced the time of the failure.

2.4 FUTURE STABILITY

The less steep terrain above the headscarp towards Mt Haast and regression of the ridge crest by the recent collapse appears have reduced the risk of future large failures from the source area. Large rock falls from the ridge southeast of Mt Haast are thought to be less likely now given the reduced source area on the ridge. There are, however, several sites where small rock falls could occur in the future, such as the steep headscarp southeast of Mt Haast, and the areas of loose debris on the upper source area (Figures 9 and 10).

2.5 GEOLOGICAL HAZARD AND RISK TO PLATEAU HUT

Following the Mt Haast rock avalanche on 21 January 2013 the Department of Conservation (DOC) commissioned GNS Science to reassess geological hazards and risk at Plateau Hut. The new assessment was intended to evaluate the risk of further collapses from the failure area on Mt Haast and similar hazard events in the future, and was completed in May 2013 (Hancox and Thomson, 2013). The results of the reassessment are summarised below.

The reassessment confirmed that Plateau Hut is founded on a ridge of greywacke (sandstone and subordinate argillite) on the eastern side of the Grand Plateau. The foundation rock is very strong and stable, shows no obvious deterioration, and is considered to be resistant to erosion and mass movement collapse. Local geological hazards (rock falls, foundation instability and collapse) are assessed to present relatively low risk to Plateau Hut. The combined hazard rating for all geological hazards (rock falls, rock avalanches, ice avalanches, foundation collapse) at the hut site is assessed as Moderate, mainly due to the potential effects of very large rock avalanches and ice avalanches triggered by strong earthquake shaking.

The most significant geological hazards that could potentially affect Plateau Hut are very large (~10^6 m^3 or greater) rock avalanches from Mt Cook, Silberhorn, and Mt Tasman, and ice avalanches from the east face of Mt Tasman during an Alpine Fault earthquake. Based on a qualitative assessment using the Australian Geomechanics Society (AGS, 2007) methodology, the risk levels for such events are assessed as ranging from Very Low to Moderate for very large rock avalanches and High for a large ice avalanche. A quantitative risk assessment of geological hazards (rock falls, rock avalanches, and ice avalanches) that could affect Plateau Hut during its nominal design life (~50 years) was carried out using the AGS (2007) landslide risk management guidelines. The results of a quantitative assessment of geological hazard events that have the potential to affect Plateau Hut in the next 50 years are summarised in Table 2.

Table 2. Quantitatively assessed risk from geological hazard events that could potentially affect Plateau Hut *(from Hancox and Thomson 2013)*.

Plateau Hut Geological Hazard Risk Assessment						
Geological Hazard Event	**Recurrence Interval (RI yrs)**	**Annual Probability $P_{(H)}$**	**Probability of Impact on Hut $P_{(S:H)}$**	**Temporal Spatial Probability $P_{(T:S)}$**	**Vulnerability of Individual $V_{(D:T)}$**	**Risk of Loss of Life $R_{(LOL)}$**
1. Very large RAV Mt Cook or Mt Haast	100.00	1.00×10^{-2}	0.01	0.50	0.01	5.00×10^{-7}
2. Larger RAV from Mt Cook or Mt Haast	329.00	3.04×10^{-3}	0.20	0.50	0.50	1.52×10^{-4}
3. Very large RAV from Mt Tasman-Silberhorn	1000.00	1.00×10^{-3}	0.10	0.50	0.10	5.00×10^{-6}
4. Large Ice Avalanche Mt Tasman-Silberhorn	329.00	3.04×10^{-3}	0.75	0.50	1.00	1.14×10^{-3}
Total Risk at Plateau Hut from geological hazards						*1.30×10^{-3}*

Notes: (1) RI and AP for Event 3 are assumed. (2) RAV refers to rock avalanche.

The most hazardous of the geological events (Table 2) is a very large earthquake-induced ice avalanche from Mt Tasman (Figure 15). The most probable triggering event for such an avalanche is likely to be an Alpine Fault earthquake centred ~30 km west of Mt Cook, which has a recurrence interval of about 329 years (Berryman et al., 2012). Rock avalanches from all potential sources are assessed to present much lower risk at Plateau Hut.

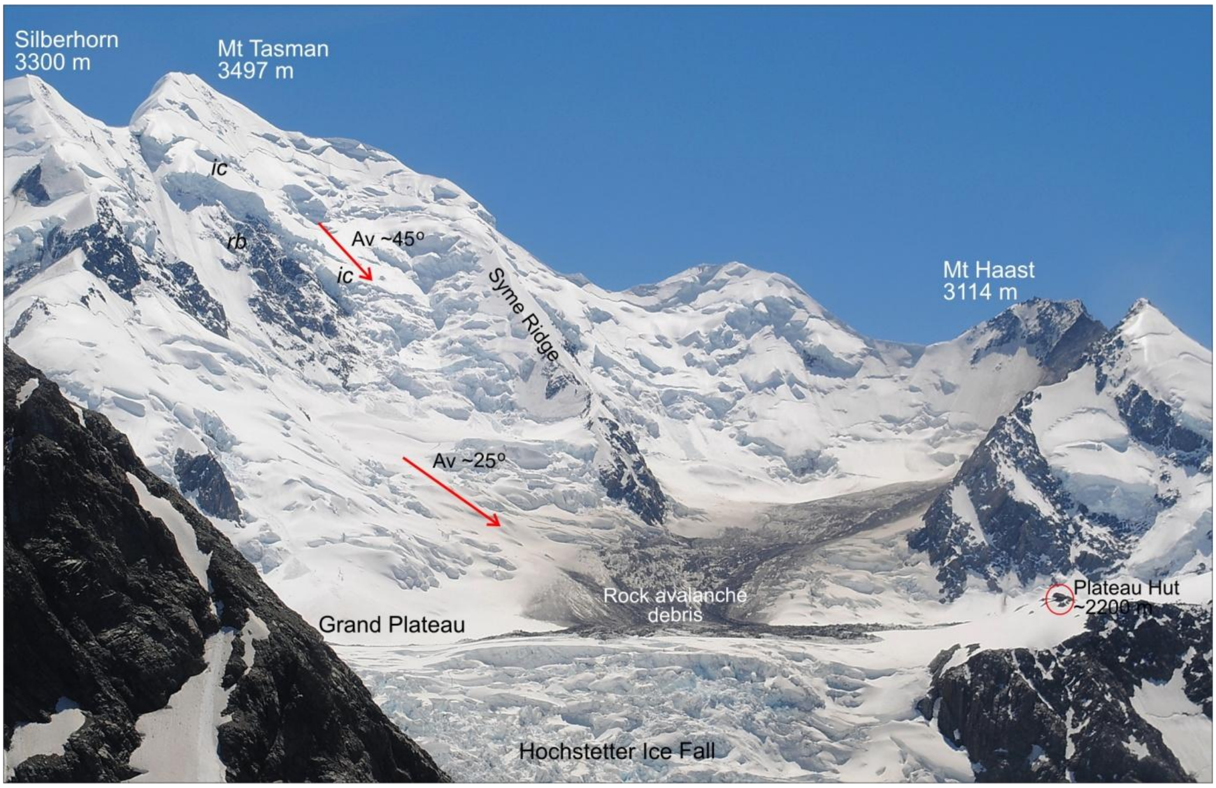

Figure 15 Aerial photo showing the topography around Plateau Hut across to peaks in the Main Divide (Silberhorn, Tasman, and Haast). The east face of Mt Tasman, 2–3 km west of Plateau Hut, has an average slope of ~45° from the rock band *(rb)* to the summit. Ice avalanches are common on this face during summer months, especially from the upper ice cliffs *(ic)*. *(Photo by R. Thomson, 22 Jan 2013)*

Strong shaking associated with an Alpine Fault earthquake (MM9 or greater in the Plateau Hut area) may trigger a very large ice avalanche on the east face of Mt Tasman 2-3 km northwest of the hut, which could runout as far as Plateau Hut (Figure 15). Such an event is speculative as there is no history of very large ice avalanches in the area, but it is realistic possibility. The annual risk (Loss of Life) for this event is estimated to be 1.14×10^{-3}. This is the highest level of risk estimated for a geological hazard at Plateau Hut.

All other geological hazards present a lower level of risk to hut occupants by at least an order of magnitude (Table 2). Large rock avalanches could occur on Mt Cook, and possibly other nearby peaks. A similar rock avalanche from Mt Cook or Mt Haast with a volume of $\sim 10^6 – 10^7$ m^3 is likely to follow paths similar to the 1991 and 2013 events, so the debris is unlikely to reach the hut. The annual LOL risk from such hazards is estimated to be 5.00×10^{-7}. A larger ($\sim 1–2 \times 10^7$ m^3) rock avalanche from Mt Cook is possible, but is also unlikely to reach the hut. The estimated LOL risk at Plateau Hut from this hazard is 1.52×10^{-4}. A very large ($\sim 10^6 – 10^7$ m^3) rock avalanche from the east face of Mt Tasman or Silberhorn is considered unlikely, even during an Alpine Fault earthquake, mainly because of lower slope gradient and better quality rock in that face (see Figure 15) compared to the source areas of failure on Mt Cook and Mt Haast. The annual risk of such a hazard at Plateau Hut is estimated to be 5.00×10^{-6}.

The annual risk of loss of life at Plateau Hut due to a large ice avalanche (1.14×10^{-3}) is higher than the acceptable or tolerable risk limit (10^{-4}/annum) for existing slopes or developments that are suggested by AGS (2007), but is within the acceptable risk level suggested by DOC for Back Country Adventure (BCA) and Risk Taker sites. Plateau Hut is classed by DOC as a BCA site, and is used almost exclusively by experienced climbers, who have a high tolerance of risk because of the activity they are undertaking. The acceptable risk threshold of 1.83×10^{-3} (annual risk of loss of life per individual), which the Department of Conservation has suggested for BCA and Risk Taker hut sites, is therefore considered to be reasonable in relation to the risk from geological hazards at Plateau Hut.

3. BALL RIDGE ROCK FALL

3.1 LOCATION AND TIME OF ROCK FALL

The rock fall on Ball Ridge was located about 5 km south of Mt Cook (Area B in Figure 1), on the ridge leading up to Ball Pass. The Ball Ridge–Ball Pass route is routinely traversed by guided tramping groups who cross the Mt Cook Range from the Tasman Valley to the Hooker Valley. The source of the rock fall is on the northwest side of the ridge crest, about 1 km southwest of Caroline Hut, and lobes of debris extended 700 m north towards the Ball Glacier (Figures 16 and 17). The failure was first inspected from the air by DOC on 11 January 2013 (Jim Spencer, pers. comm.), but is believed to have occurred during the rainstorm on 9–10 January when about 383 mm of rain fell at Mt Cook Village (Table 1).

Figure 16 Aerial view of the rock fall on the northwest side of Ball Ridge, about 800 m east of Ball Pass.

3.2 GEOLOGY OF THE ROCK FALL SITE

The bedrock in the Ball Ridge area is greywacke, with bedding generally dipping steeply to the northwest (Cox and Barrell, 2007). Bedding variations are present, however, and at the rock fall site bedding dips steeply to the southeast, and just south of the headscarp the bedding locally is near vertical and strikes normal to the ridge line (Figure 17).

Both sandstone and argillite are present in the rock fall area as shown in the cross section of the site (Figure 18), and an aerial photo of the source area and headscarp (Figure 19). The latter shows that each of these rock types has a different fabric, joint development, rock strength, and impact on slope integrity and debris characteristics. Aerial observations and photos show that the rock fall site lies within an old (geologically) zone of folding, faulting, and shearing, which may also be part of the same fault system which intersects the ridge between Mt Haast and Mt Dixon (see Section 2.2).

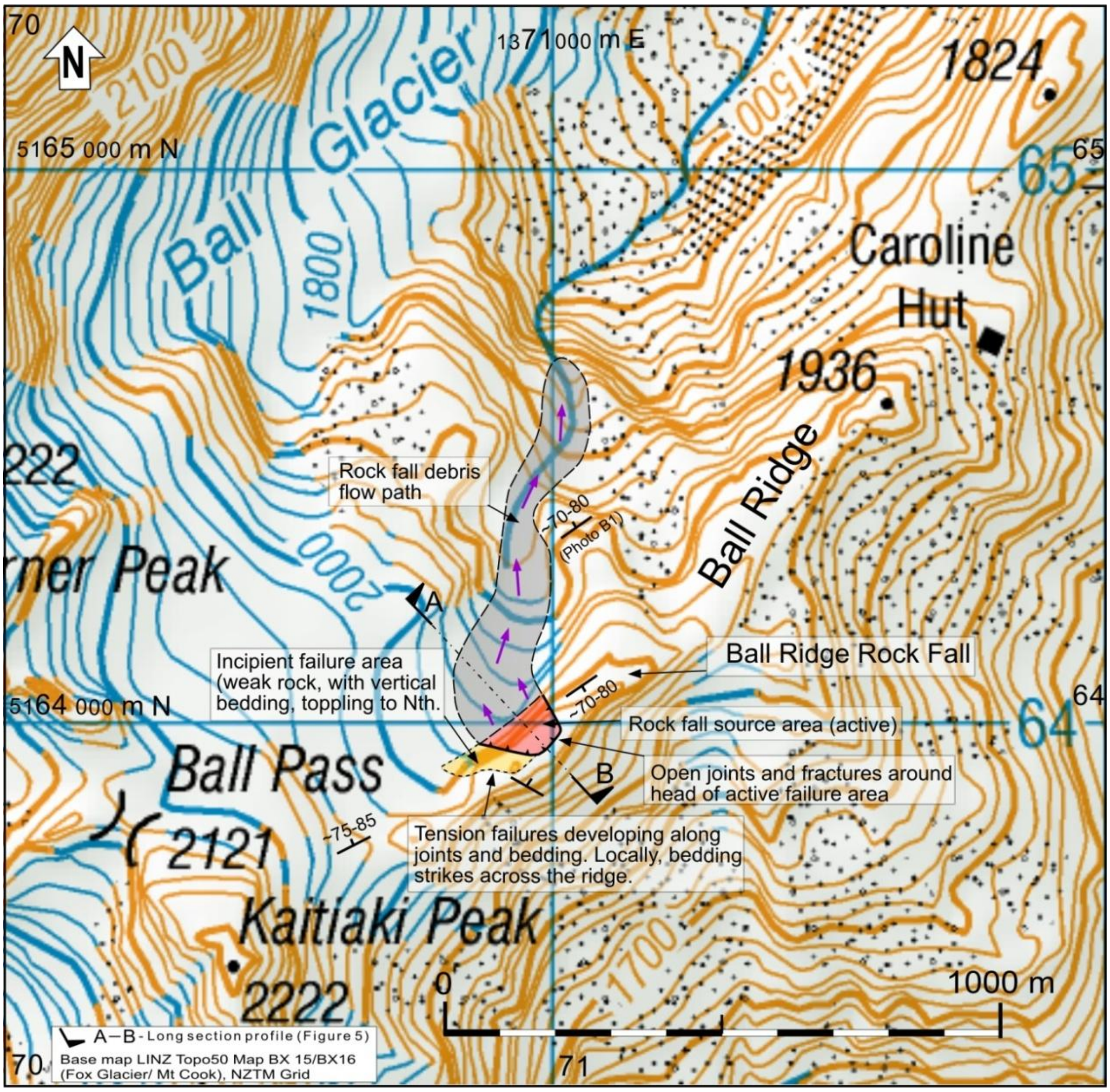

Figure 17 Map of the Ball Ridge rock fall source area and debris lobe, with some geological observations.

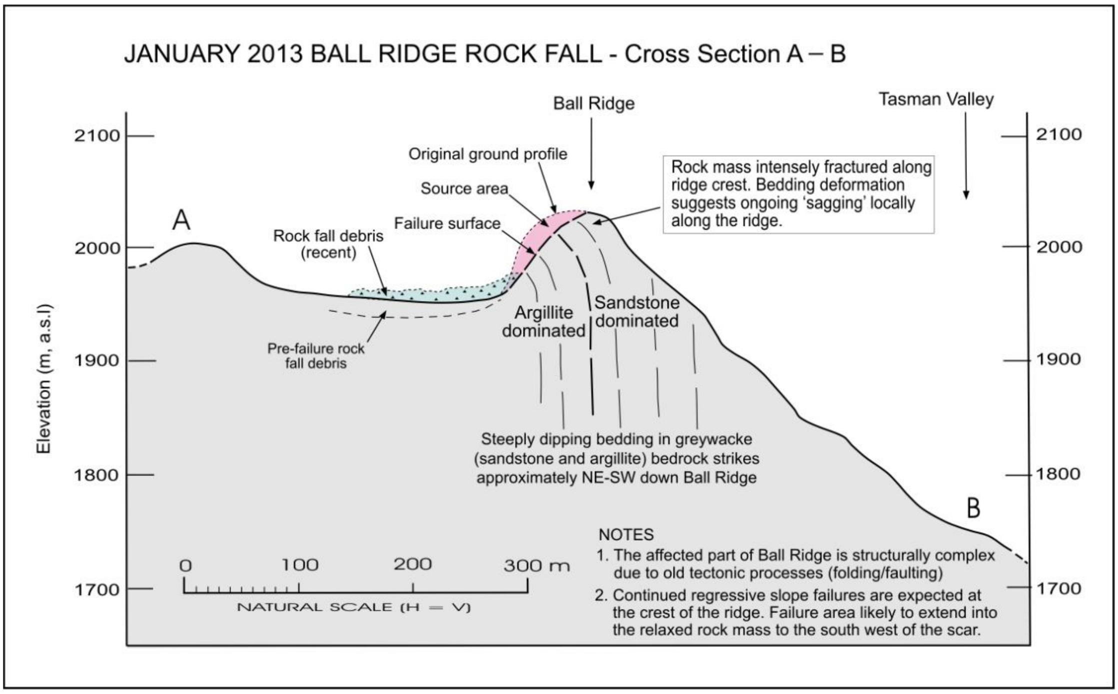

Figure 18 Geological cross section A-B through the January 2013 rock fall on Ball Ridge.

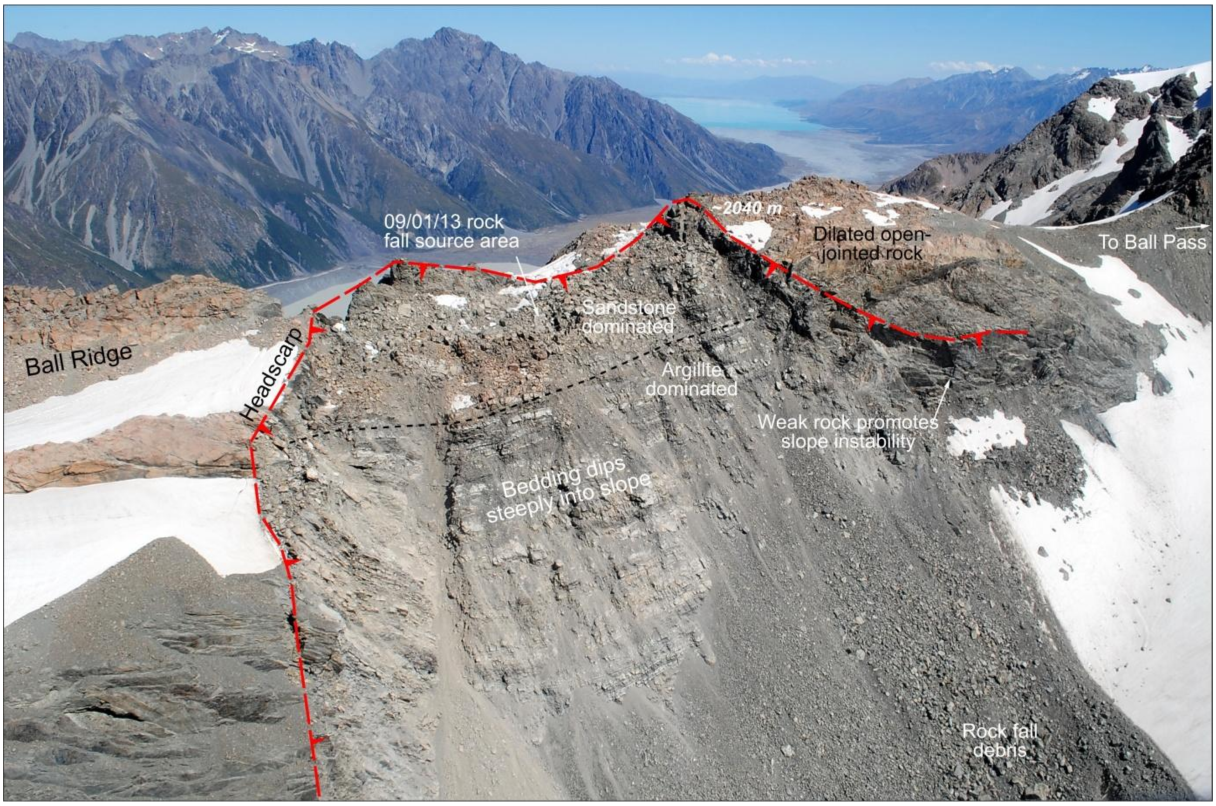

Figure 19 Aerial view of the Ball Ridge rock fall looking south and showing the rock types and characteristics in the source area, where the bedding dips steeply into the slope. The failure process is mainly by toppling, and is propagating to the southwest where the rock is observed to be dilated and open-jointed.

3.3 SIZE OF ROCK FALL

Figure 17 and Figure 18 illustrate the approximate plan and cross sectional dimensions of the rock fall area. From these figures it is estimated that the rock fall source area is ~100 m across and 20 m deep, and the ~700 m long lobe of rock fall debris that extends towards the upper Ball Glacier covers an area of about 100,000 m^2. Assuming that the average depth of the debris is between 1-2 m, the volume of the rock fall is estimated to be about 150,000 m^3.

3.4 FAILURE MECHANISM

The location of the rock fall source on the ridge crest suggests that the instability has been initiated by glacial erosion, and has accelerated due to glacial retreat over the last 100 years. Figure 19 shows the area of weak, argillite-dominated rock mass in the source area, where bedding dips into the slope and the failure process is mainly by toppling. The dilated, open-jointed rock around the headscarp (red dashed line in Figure 19) shows that the failure is likely to propagate to the southwest, and also upslope (east) across the ridge line where it has already caused a drop in the ridge profile. This process is likely to be ongoing.

3.5 POTENTIAL FOR FUTURE RIDGE FAILURES

At the northern end of the recent rock fall area on Ball Ridge there are no obvious stress features on the ridge, but at the southwest end there is clear evidence of toppling in the argillite, and open joints and bedding fractures in the sandstone (Figure 19). This indicates the potential for further retrogressive failures of the headscarp, especially at the southwest end. These failures may occur during future rainstorms, strong earthquake shaking, or possibly without an obvious trigger.

4. DISCUSSION

The Ball Ridge rock fall and Mt Haast rock avalanche in January 2013 represent the most recent large slope failures in the Southern Alps of New Zealand. Although it was not witnessed, the ~150,000 m^3 rock fall on Ball Ridge, which occurred during the 9-11 January rainstorm, was triggered by heavy rainfall when about 400 mm rain fell at Mt Cook Village over 3 days. Failures of this type can be expected following such an extreme weather event.

An earlier rainstorm from 1-3 January, when more than 500 mm was recorded at Mt Cook Village (Table 1), may also have contributed to the rock fall on Ball Ridge. The 1-3 January storm affected the whole of the West Coast of the South Island from Fiordland to Hokitika, and is reported by DOC (Cornelia Vervoorn pers. comm.) to have triggered other large rock falls on the Smyth Range and flooding in the Wanganui River 75 km northeast of Mt Cook.

By contrast, the rock avalanche from Mt Haast on 21 January occurred during fine weather, 12 days after the Ball Ridge rock fall, but was preceded by two rainstorms earlier in the month, and 126 mm of rain over the 7 days prior to the failure. It is probable, therefore, that although the Mt Haast rock avalanche occurred in the middle of a fine day without an obvious trigger, heavy rainfall may have strongly influenced the time of the failure.

The rock avalanche from Mt Haast was the largest landslide in the Mt Cook region since the Mt Cook rock avalanche in 1991 (Hancox, 1991; Mc Saveney, 2002). That failure and the rock falls on Ball Ridge and the Smyth Range on the West Coast in early January 2013 were the latest of a series of large rock falls and rock avalanches in the Southern Alps in the last 32 years (Table 3).

Table 3. Significant rock falls and rock avalanches in the Southern Alps over the last 32 years[1].

Name	Date	Volume	Trigger[2]	Reference
Franz Josef Glacier	1981	~10^6 m^3	N (Rainfall?)	GNS Records (G Hancox)
Mt Cook	14/12/1991	10-14 x 10^6 m^3	N	Mc Saveney 2002
Mt Fletcher	02/05/1992	>10^6 m^3	N	Mc Saveney 2002
Mt Fletcher	16/9/1992	>10^6 m^3	N	Mc Saveney 2002
Murchison Glacier	25/12/1995	10^5-10^6 m^3	N	Allen et al. 2011
Mt Thomson	22/2/1996	10^5-10^6 m^3	N	Mc Saveney 2002
Mt Adams	6/10/1999	~10-15 x 10^6 m^3	N	Hancox et al. 2005
Mt Beatrice	23/11/2004	10^4-10^5 m^3	Rainfall (?)	Allen et al. 2011.
John Inglis	15/12/2006	~3 x 10^6 m^3	N	Hancox et al. 2007; Thomson 2007
Young River	28/8/2007	~11 x 10^6 m^3	N	Massey et al. 2011
Vampire Peak	07/1/2008	10^5-10^6 m^3	N	Cox et al. 2008
Douglas Peak	18/2/2008	10^4-10^5 m^3	N	Allen et al. 2011.
Mt Spencer	07/4/2008	10^4-10^5 m^3	N	Allen et al. 2011.
Mt Halcombe	24/4/2008	10^4-10^5 m^3	N	Allen et al. 2011.
Franz Josef Glacier	13/10/2011	~10^5 -$10^6$$m^3$	N	GNS Records/YouTube video
Smyth Range	1/1/2013	10^4-10^5 m^3 or >	Rainfall	This study, DOC/GNS Records
Ball Ridge	09/1/2013	10^5 m^3	Rainfall	This study
Mt Haast	21/1/2013	2 x 10^6 m^3	N (Rainfall?)	This study

[1] Rock avalanches and other landslides triggered by earthquakes (e.g., in 1929, 1968, and 1994) are excluded from this list.
[2] N – Indicates landslide events with no apparent triggering event.

This record supports a conclusion that large rock falls and rock avalanches in alpine areas have become more frequent in the last 30 years and have increased noticeably since 1991. This change has occurred against a background of the widely-reported increased global temperatures of almost 1°C and glacial recession during the 20th century.

Reduced stability of steep bedrock slopes is recognised as one impact of warming in alpine areas (Huggel et al., 2010). In the Swiss Alps extremely warm temperatures have been linked to increased rock fall activity over the last 50 years, but this effect is not so evident in New Zealand (Allen and Huggel, 2013). Instead, in the Southern Alps some recent slope failures have been preceded by large temperature fluctuations, from extremely warm to freezing, as occurred before the 1991 Mt Cook rock avalanche, and high levels of precipitation (150 to >500 mm/day) is likely to have triggered recent large rock falls on the Murchison Glacier, Mt Beatrice, and Ball Pass (Table 3).

The results of the present study support these observations, particularly in relation to rainfall triggering of the Ball Ridge rock fall, and the influence that temperature fluctuations and high precipitation appears to have had on the timing of the Mt Haast rock avalanche. We believe that there is ample evidence to show that climatic factors and changes have caused rock avalanches and other landslides in the Southern Alps in the past, and that the frequency of these failures has increased in recent decades. However, as shown by Allen et al. (2011) we also believe there is insufficient evidence to determine precisely how much of this change is due to ice recession, permafrost degradation, and other climatic forcing factors.

Slopes in the high mountains of New Zealand clearly show signs of increased instability over the last 50 years, including evidence of rock mass dilation and opening of joints and fractures along bedding, and rock mass creep as observed on the Mt Dixon-Mt Haast ridge has also increased. Large-scale deep-seated rock mass creep is also evident in parts of Aoraki/ Mt Cook National Park, such as the western slopes of the Sealy Range which are failing onto the Mueller Glacier, and slopes adjacent to the Douglas, Whymper, and Spencer glaciers in response to glacial debutressing (McColl and Davies, 2012).

Weak bedrock and glacial steepening of slopes have caused a number of high mountain ridges to fail without an obvious trigger. Whatever the role climate has played in this process, these types of ‘spontaneous’ failures are expected in the foreseeable future, but are more likely to occur during high rainfall events and strong earthquake shaking especially the next Alpine Fault earthquake which has about a 30% probability of occurring in the next 50 years (Berryman et al., 2012). An Alpine Fault earthquake (M 8 or >) centred 30 km west of Mt Cook is expected to cause shaking of intensity MM 8-10 in the Mt Cook area (Hancox and Thomson, 2013). Studies of historical co-seismic landsliding in New Zealand (Hancox et al. 1997, 2002) indicate that such an event would cause numerous rock falls and rock avalanches in the Southern Alps, many of which could be as large or larger than the 1991 Mt Cook rock avalanche (10^6–10^7 m^3 or >).

Given the marked climatic changes that have occurred over the last 100 years, particularly glacial retreat and higher temperature, and the increased instability of alpine slopes in recent decades, it is likely that landslides triggered by the next Alpine Fault earthquake in the central Southern Alps will be more numerous and possibly larger than those triggered by the last Alpine Fault earthquake in 1717. That event occurred during the Little Ice Age, and the higher snow and ice levels of that time may have provided more glacial buttressing of slopes, and so reduced the number of co-seismic slopes failures in the high mountains.

5. CONCLUSIONS

The rock avalanche from the ridge between Mt Haast and Mt Dixon in Aoraki/Mt Cook National Park at 2:09 pm on 21 January 2013 originated in very weak rock, associated with a fault zone developed sub-parallel to bedding in greywacke bedrock. The avalanche was initiated by a collapse of the ridge crest at an elevation of about 3040 m with an estimated volume of up to ~1 million m^3. The falling rock debris entrained a large volume of snow and ice as it flowed down the snow névé south of Mt Haast with an average velocity of up to 160 km/hour. Although the rock avalanche occurred during fine weather without an obvious trigger, heavy rainfall (> 900 mm) during two rainstorms in early January is believed to have strongly influenced the time of the failure.

The rock avalanche ran out 2.9 km on to the Grand Plateau and came to rest about 200 m west of Plateau Hut near the top of the Hochstetter Icefall at an elevation of ~2100 m. The avalanche debris (boulders, gravel, and sand up to 5 m thick) covers an area of about 0.8 km^2 on the Grand Plateau, with an estimated total volume of ~2 million m^3, of which about half is snow and ice. The shaking caused by the rock avalanche was recorded on several GeoNet seismographs at distances of 29–139 km from the source, and is calculated to have had an average local magnitude of M_L 2.25.

This recent collapse appears have reduced the risk of future large failures from the ridge between Mt Haast and Mt Dixon because of the reduced source area, although there are several sites where small rock falls could occur in the future, such as the overhanging head scarp on the western side, and the areas of loose debris on the upper failure zone. Repeat failures of similar size to the recent collapse are unlikely, but minor retrogressive rockfalls can be expected in the future. The annual risk (loss of life) at Plateau Hut from future rock avalanches from the source area on Mt Haast is estimated to be very low ($\sim10^{-7}$).

The ~150,000 m^3 rock fall on the popular Ball Ridge tramping track to Ball Pass occurred in an area of weak, argillite-dominated rock during the 9-10 January 2013 rainstorm when 383 mm rain was recorded at Mt Cook Village. . Although the rock fall was triggered by rainfall, the slope was made more susceptible to failure by erosion and glacial retreat over the last 100 years. The rock fall area on the northwest side of the ridge is expected to increase in size over time, but is not expected to prevent use of the Ball Ridge track if further large collapses occur, although the route may become more difficult to use.

The Ball Ridge rock fall and Mt Haast rock avalanche in January 2013 are the most recent large rock slope failures in the Southern Alps, providing further evidence of increased slope instability over the last 50 years. Given the marked climatic and physiographic changes that have occurred, large slope failures in alpine areas are expected to continue in the future, particularly during rainstorms and strong earthquake shaking. The next Alpine Fault earthquake is expected to trigger numerous large rock falls, rock avalanches, and other types of landslides in the Southern Alps.

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GNS SCIENCE
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www.gns.cri.nz

Principal Location

1 Fairway Drive
Avalon
PO Box 30368
Lower Hutt
New Zealand
T +64-4-570 1444
F +64-4-570 4600

Other Locations

Dunedin Research Centre
764 Cumberland Street
Private Bag 1930
Dunedin
New Zealand
T +64-3-477 4050
F +64-3-477 5232

Wairakei Research Centre
114 Karetoto Road
Wairakei
Private Bag 2000, Taupo
New Zealand
T +64-7-374 8211
F +64-7-374 8199

National Isotope Centre
30 Gracefield Road
PO Box 31312
Lower Hutt
New Zealand
T +64-4-570 1444
F +64-4-570 4657