Institute of Geological & Nuclear Sciences Limited

The fatal Ramsay Glacier rockfall of 9 November 2002

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by M. J. McSaveney, T. R. Davies & G. L. Ashby

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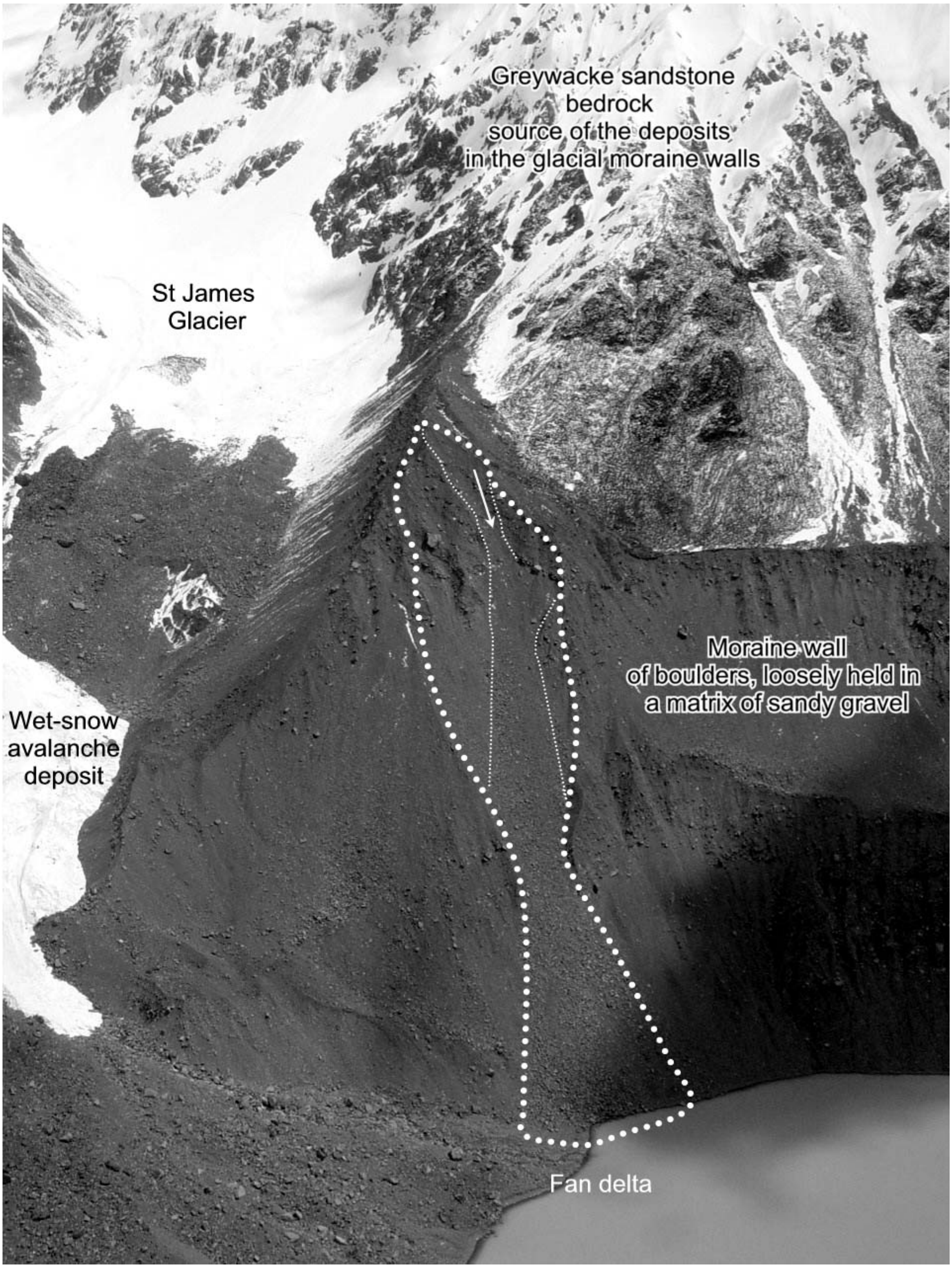


Frontispiece Hourglass shaped site of the fatal rapid debris fall (rockfall) that killed Simon Hassall on 9 November 2002. Some 5–10 thousand cubic metres of sand, gravel and boulders probably fell from the top right of the scar. Mr Hassall was traversing the lake edge from right to left and was within a few seconds of reaching the safe fan-delta in the centre foreground when one of many large boulders, travelling at 150 km/hr or more, knocked him into the lake. St James Glacier is at the upper left. Ramsay Glacier is to right of photograph.

ABSTRACT

Recession of Ramsay Glacier since the late 19th Century has formed a proglacial lake at the glacier terminus in the headwaters of Rakaia River, Canterbury. The lake is flanked to east and west by high, steep walls of unconsolidated, bouldery, glacial moraine. The lake shore comprises screes of large boulders that have fallen from the moraine. The access route to Ramsay Glacier traverses the foot of these screes for some 700 metres along the lake shore, and users of the route are exposed to the danger of rocks falling from the moraine wall.

A fall of some thousands of cubic metres of bouldery gravel while two trampers were traversing the route on the afternoon of 9 November 2002, killed Simon Raymond Hassall, 26. His companion who was a few metres ahead of him escaped unscathed. At the time of the accident, they had all but completed their traverse along the foot of the unstable moraine wall, which they had traversed an hour or so earlier in the opposite direction without incident. Mr Hassall had alerted his colleague to watch for rockfalls only minutes before the pair saw a huge piece of debris detach from the top of the moraine wall 270 metres above them. The detached mass contained many large boulders, with hundreds being several metres and more across. Mr Duggan reached safety. One or more boulder fragments fatally injured Mr Hassall and knocked him into the lake. It is likely that the rock that stuck him weighed several tonnes and was travelling in excess of 150 kilometres per hour.

Technically, the process of collapse of the glacial moraine wall is called dry ravelling, and the collapse itself was a very rapid, dry, debris fall. This collapse was on such a large scale, and with such large boulders, that it behaved exactly as would a large rockfall. Enormous boulders hopped and skipped down the slope, emitting huge shards of fractured rock as they hit other rocks. It is remarkable that Mr Duggan escaped the flying rocks without injury as large rock fragments sprayed up to 40 metres beyond the foot of the slope. His escape indicates that Mr Hassall possibly was only a few seconds from safety when he was hit. The event was not something that they could have outrun.

The rockfall danger was recognised by the deceased, likely because he saw the evidence of shattered large boulders that they were walking among. Although he could see the sizes of fallen boulders, he was unlikely to have been aware of how many might fall at once, or that the likelihood of rockfalls had been increased by recent wetting of the moraine wall by rain.

The pair entered the valley to obtain a long-range weather forecast, taking advantage of cell-phone reception at higher altitude in the Ramsay area.

There is no practical alternative to this dangerous route, but users should be made aware that they use it at their own risk, and that it is more dangerous during and shortly after rain.

KEYWORDS Landslide, rockfall, debris fall, Ramsay Glacier, fatality

1.0 INTRODUCTION

1.1 Background

On the afternoon of 9 November 2002, Simon Raymond Hassall, 26, was killed by a large fall of boulders while traversing the foot of a rockfall scree on the western side of the proglacial lake at Ramsay Glacier in the headwaters of Rakaia River, Canterbury (grid ref E2340360 N5768490, Infomap 260-J35 Arrowsmith) (Frontispiece, Figs 1a, b, 2a, b). He and his tramping companion, Eric Duggan, were returning to Reischek Hut along the side of the lake after climbing part way up the Ramsay Glacier to make a cell-phone call for a weather report. Mr Duggan survived the event unscathed.

1.2 Site Inspection

As part of the GeoNet natural geological hazards monitoring contract between the Institute of Geological & Nuclear Sciences (GNS) and the Earthquake Commission, a response team is to investigate any incident of land instability involving loss of life. This investigation was made under this contract. The response team consisted of Dr Mauri McSaveney (GNS), Professor Tim Davies, Lincoln University, and Mr Gordon Ashby, URS New Zealand Ltd. We flew to the site by helicopter on 18 November 2002, and were on site for about an hour.

We inspected the site from the air and from safe ground adjacent to the fatal rockfall. We did not venture onto the rockfall scree. Although no rocks fell in this area during our visit, we judged it too unstable and too liable to further large collapses without warning or adequate time for us to escape. The sounds of falling rocks were heard frequently in the valley during our brief visit in fine weather.

1.3 Scope of report

This report details our findings concerning the stability of the slopes in the vicinity of the fatality, and of the behaviour of the falling blocks. It is not directly concerned with the death of Mr Hassall.

1.4 Acknowledgements

Logistics for this investigation were funded by the Earthquake Commission through the GeoNet project. We gratefully acknowledge the assistance of Mt Hutt Helicopters Ltd of Pudding Hill. Don Eggleston of the New Zealand Police, Methven provided additional information.

Grant Dellow and Simon Cox reviewed this report.

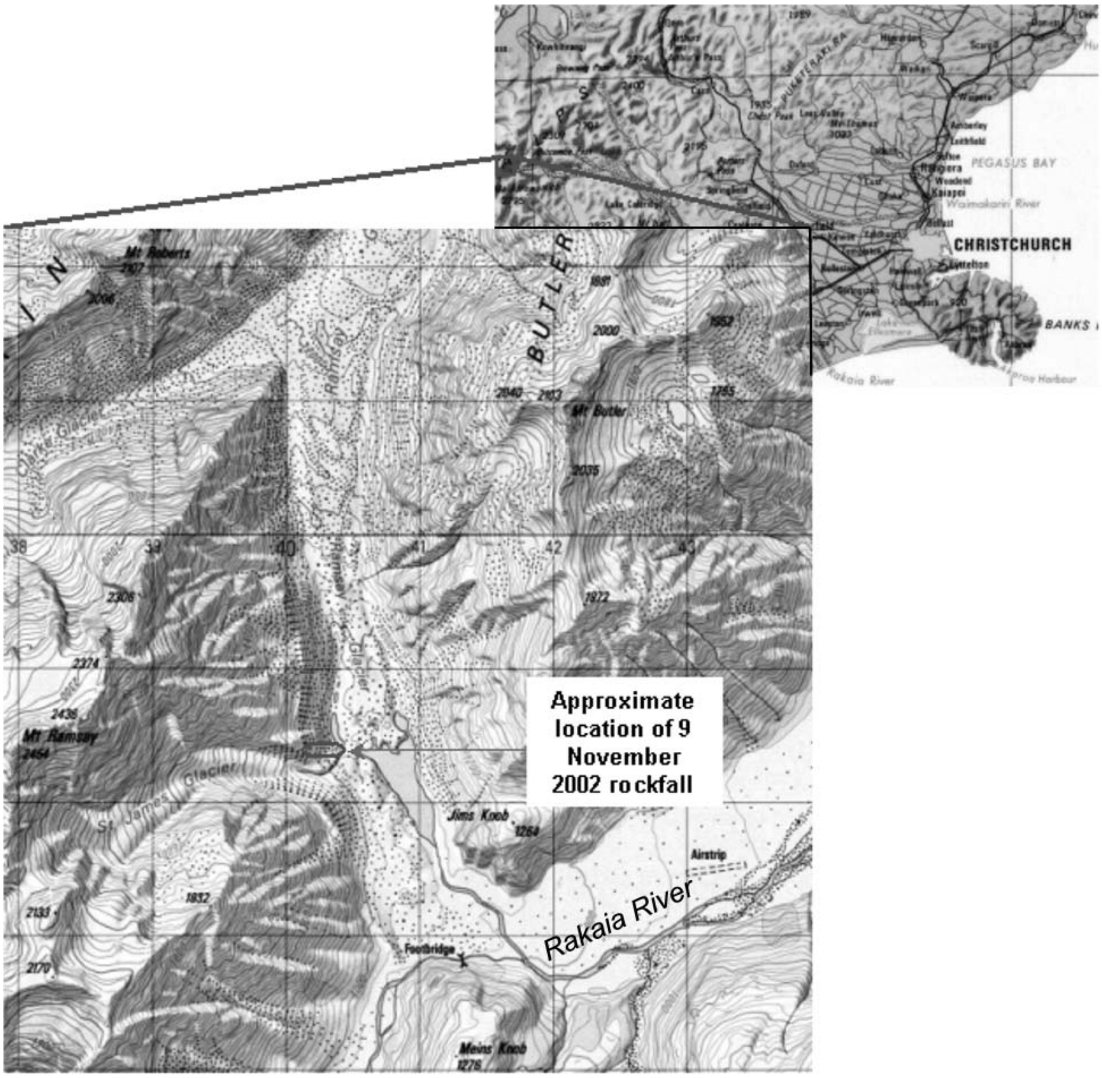


Figure 1a Site location map. Fatality occurred at arrowhead. Lake is shown as mapped on Infomap 260-J35 as of March 1986. See Figure 1b for lake as of November 2002. Reischek Hut is about 900 m east of the lower right border of the map (see figure 1b). The access route from there to Ramsay Glacier crosses the Lyell Glacier branch of the Rakaia River at Footbridge and follows the west side of the lake to Ramsay Glacier. (contour map is part of Infomap 260-J34 and J35). Grid is 1 km square.

2.0 SITE LOCATION AND GEOLOGY

2.1 Location names, glacier recession and geomorphology

New Zealand geographic names have not kept pace with the recession of Ramsay Glacier, which contributed water directly to Rakaia River when the glacier was named over 140 years ago. In the last 100 years, there has developed a short Ramsay branch of Rakaia River and a lake between this river and Ramsay Glacier (Fig. 1b). Due to continued glacier recession since February 1986, the unnamed lake now is about 700 metres longer than shown on the published topographic map. The approximate extent of the lake in November 2002 is shown in Figure 1b.

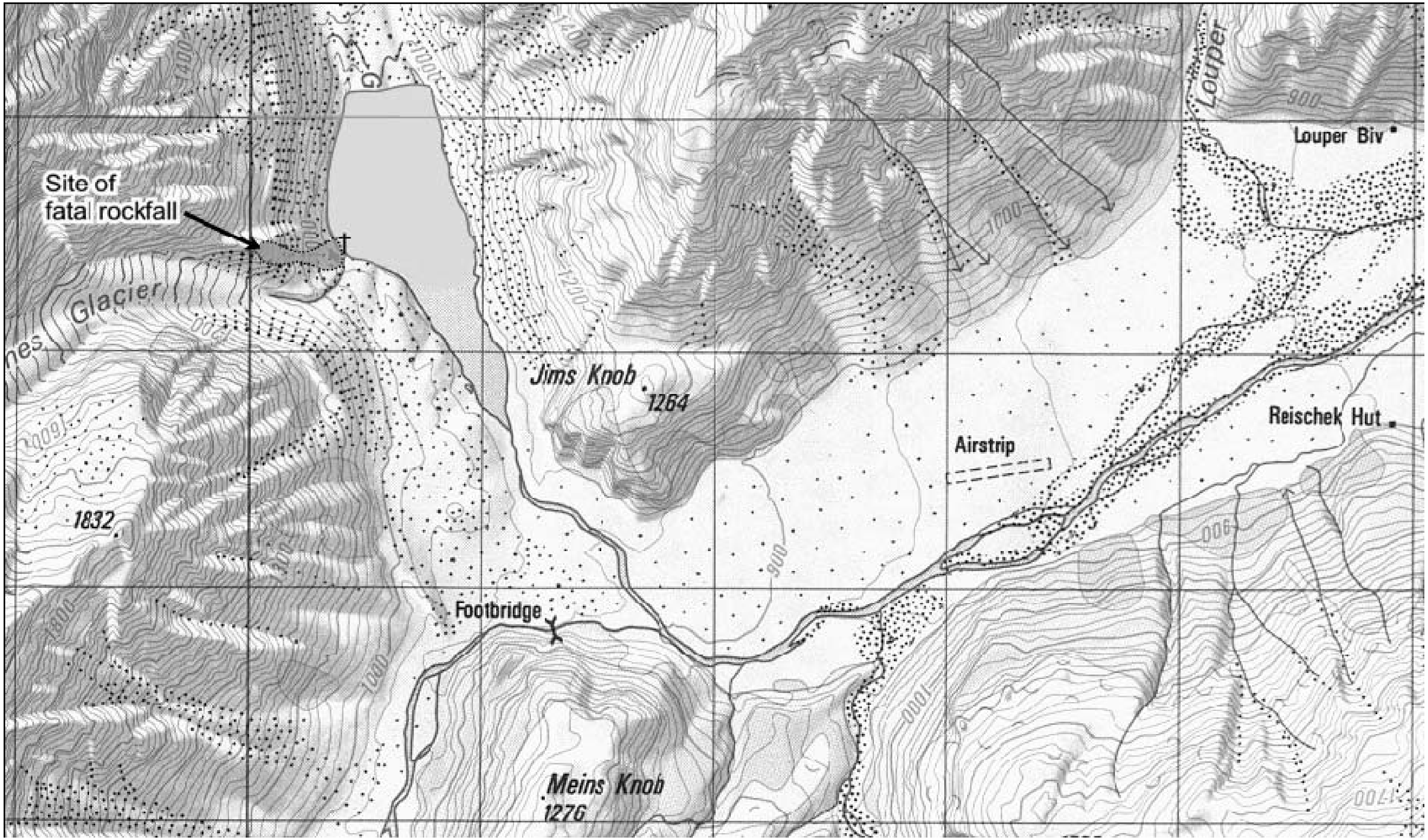


Figure lb Detailed site location map (portion of Infomap 260-J35). Lake at terminus of Ramsay Glacier is corrected approximately to its extent in November 2002. Left gridline is 2339000E, right is 2345000E. Lower gridline is 5766000N, upper is 5769000N. Grid is 1 km square.

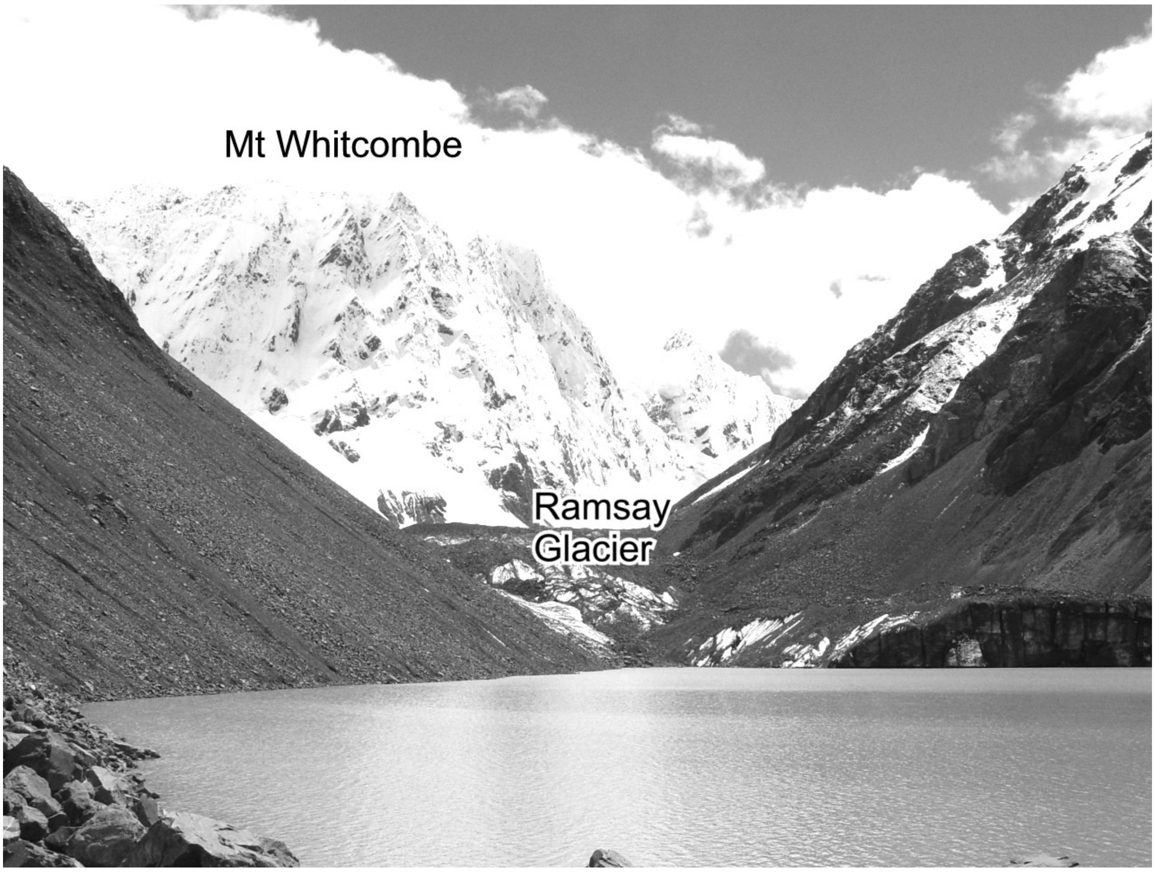


Figure 2a The access route to Ramsay Glacier, at the head of the lake, traverses the screes on the western, left, side of the lake. For the entire length of route over the screes, people are exposed to a risk of being hit by large boulders falling from the abandoned lateral moraine wall, deposited by Ramsay Glacier prior to 150 years ago. Debris from fatal rockfall forms the left foreground.

The accident site lies on the currently accepted route from the Rakaia valley to Ramsay Glacier. It is on the western shore of the lake, adjacent to a fan-delta being built by the stream draining St James Glacier (Frontispiece). The rockfall hazard to the Ramsay Glacier route has developed entirely since 1986, after continuing glacier recession cut off safe access to the glacier and forced people using the route to traverse the foot of an up-to 270-metre-high, steep wall of glacial moraine at the foot of Mt Ramsay (Frontispiece, Fig. 1). If further glacier recession exposes a precipitous bedrock slope at the lake shore, the route could be rendered impassable, but the current high rate of growth of rockfall screes may prevent this.

The moraine wall (Fig. 3) is made of weakly consolidated bouldery, sandy gravel, very weakly held together by coatings of silt. Many of the boulders exceed one metre across and some exceed 10 metres. The upper and middle slopes of the wall stand at slope angles of 50 to 60° (Fig. 4). The moraine was deposited by the Ramsay Glacier during the 18th and 19th centuries. The lower part of the wall is mantled by a series of coalescing screes along the lake shore (Figs 2, 5). These screes were formed by dry ravelling of the loose moraine debris, after glacier recession removed the ice that previously supported the moraine. The screes stand at slope angles of 25 to 35° and are at the margin of stability (angle of repose) for their loose materials.

Figure 2b Aerial view to north of Ramsay Glacier. Approximate extent of lake in November 2002 is shown by the dotted line. Arrows mark the location of the fatal debris fall. The access route to the glacier traverses the western (left) side of the lake. For the entire length of route over the screes between the black arrow and the glacier, people are exposed to a risk of being hit by large boulders falling from above. The valley wall on the eastern (right) side of the lake lacks deposits of bouldery glacial moraine, but the highly fractured bedrock there is a source of rockfalls that were heard many times during our one-hour site inspection. There is no access route to the lower glacier not exposed to a rockfall hazard. Frequent rockfalls have created these screes that make the lakeshore route passable. Photograph taken in 1995 by Trevor Chinn.

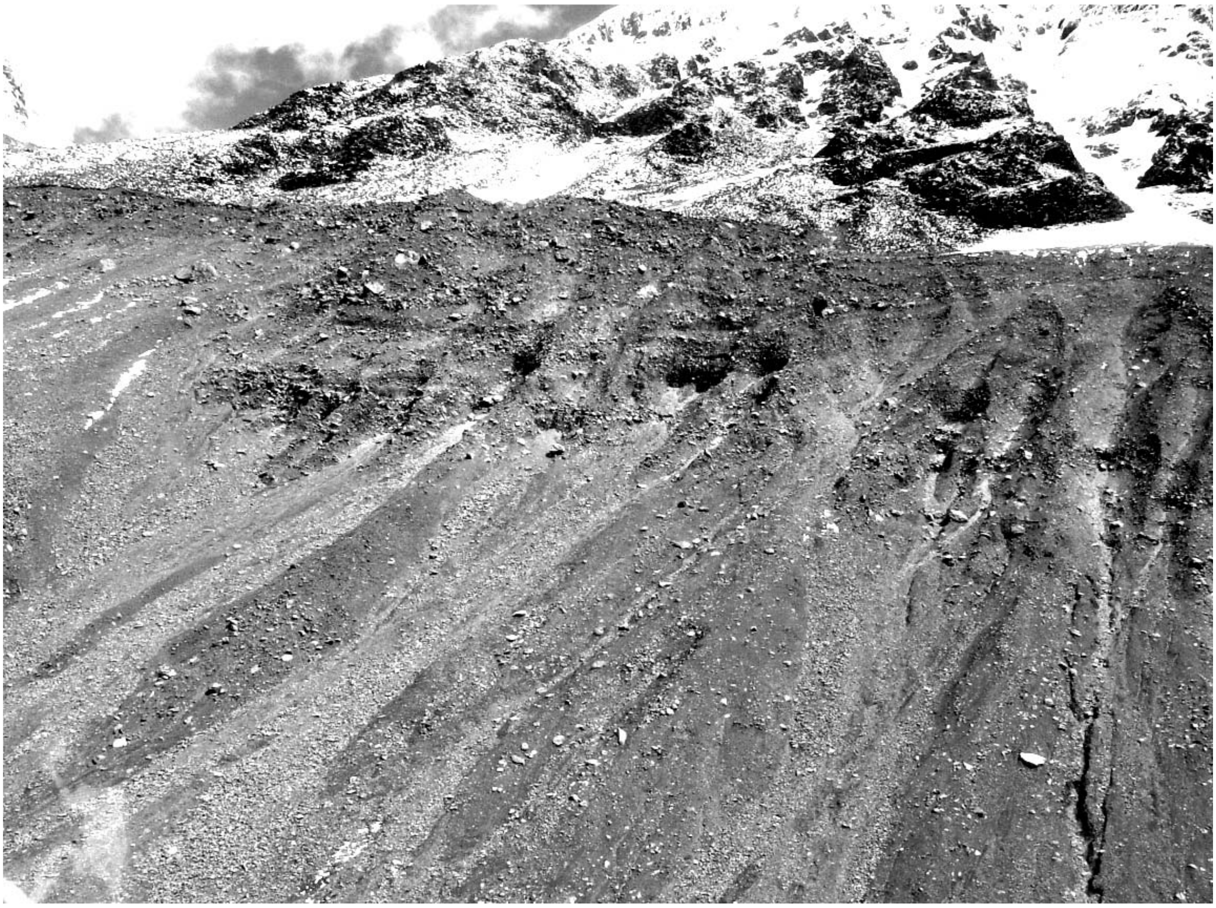


Figure 3 View of the upper moraine wall north of the site of the fatal debris fall (out of view to left). The moraine material consists of large boulders loosely held in a sandy gravel matrix. It looses much of its low strength when wet. Loosened debris cascades from the upper wall to form the bouldery scree slopes at the lake shore. The larger boulders in this view are around 10 metres across. The east face of Mt Ramsay forms the background.

At the southern end of the section of route that traverses the rockfall screes is the former junction of Ramsay and St James Glaciers (Fig. 1a). Here, the moraine wall is higher than elsewhere along the valley side because it merges with the lateral moraine wall of St James Glacier (Frontispiece, Figs 1b, 6). The moraine crest at this junction is some 270 metres above the lake. The exposed deposits have a strong fabric shown by long axes of boulders dipping downward, out of the slope at angles of about 30° (Fig. 5) representing the angle of repose for the loose material when it was deposited on the moraine. The upper portion of the eroding moraine face itself now stands at an angle of 40 to 45°. Much of this 270-m high face appears to be made up of a coalesced group of failure scars feeding a single scree slope below. There is a narrowing in the midslopes that gives the landform the appearance of an hourglass (Frontispiece). The upper part of the slope has a cluster of roughly semi-circular backscarps and concave basins (Frontispiece) indicating zones of landslide depletion. The backscarps of these source areas stand at slope angles of around 40 to 45°. The materials are sandy gravel forming the matrix between many very large boulders. Below the "neck" of the hourglass, a boulder scree has accumulated that extends to the bottom of the lake. The scree is surfaced

Figure 4 View to north along the abandoned lateral moraine wall of the Ramsay Glacier. The scree where the fatal rockfall (debris fall) occurred is outlined. Circle indicates approximately where Mr Hassall was hit by a boulder and knocked into the lake.

mostly by huge to enormous boulders (Fig. 7), representing the coarser debris transported downslope from the source area. The larger boulders falling from the upper slope reach to the base of the rockfall scree (Fig. 8) and out into the lake. The accident occurred at the southern foot of the scree below the scar (Fig. 1b).

The route to Ramsay Glacier traverses amongst the boulders at the foot of the slope (Figs 2, 5). It is not a marked track or a discernible path - the screes are too active to retain evidence of human passage – but it is a logical route.

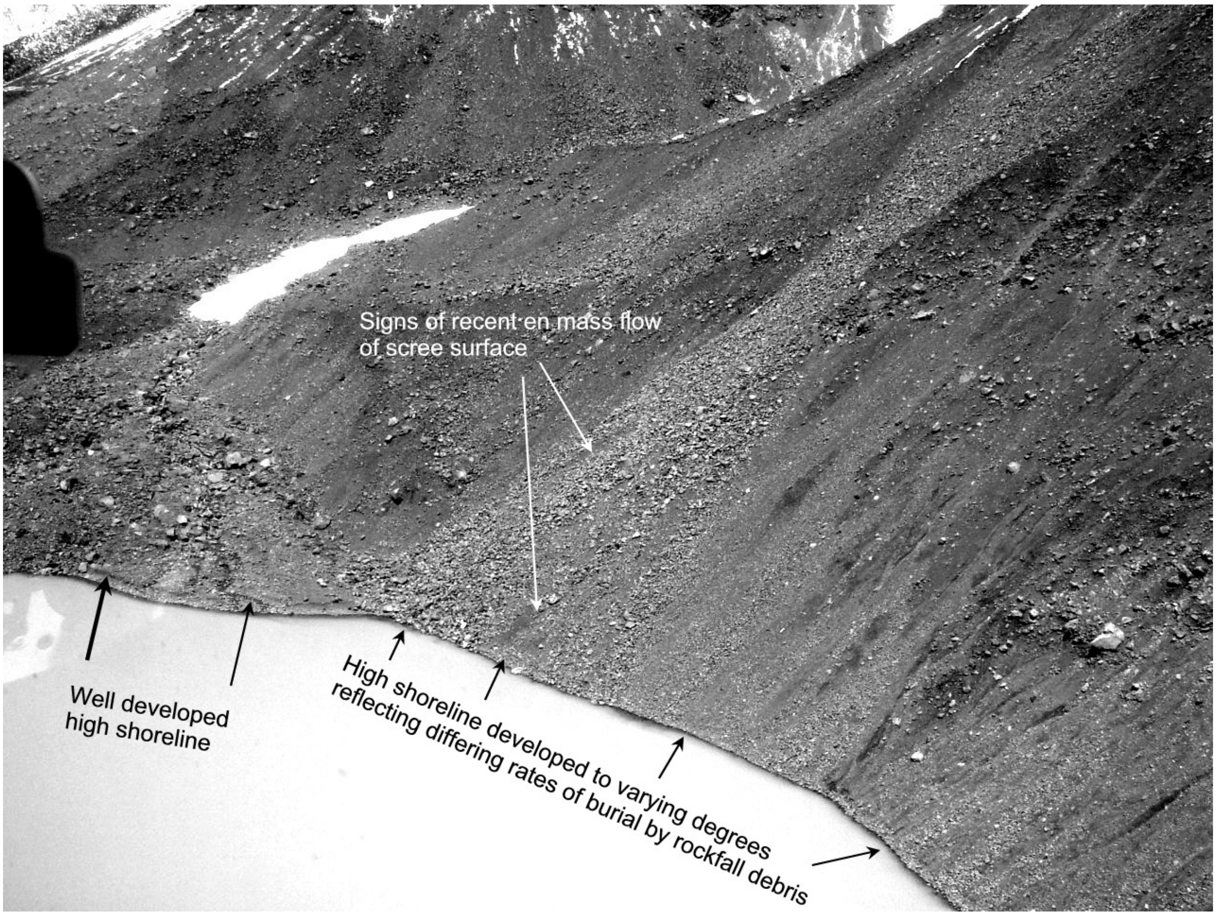


Figure 5 The edge of the lake showing accident site (circled) at the junction of the rockfall scree with the fan-delta. The faint line parallel to the lake shore is a shoreline formed when the lake level is higher during heavy rain. The route to Ramsay Glacier (out of view some 500 metres to right foreground) traverses at about this level. White arrows point to areas of recent *en masse* flow of the scree surface.

2.2 Bedrock geology

The general geology of the basement rocks in this area is Torlesse greywacke, which is a fine-grained, highly indurated, muddy sandstone, and subordinate interbedded muddy siltstone. The bedrock, however, was not involved in the slope failure at Ramsay Glacier.

Failure was entirely confined to the unconsolidated deposits of glacial moraine. The boulders falling from the moraine at the accident site are locally derived from the Torlesse greywacke of the south-facing wall of Mt Ramsay. In the past few hundred years or so, they have fallen from Mt Ramsay onto the surface of St James Glacier. They then have been carried by the ice before being deposited at the glacier margin to form the loose deposits of the lateral moraine of St James Glacier. They are of unweathered to slightly weathered, very strong to extremely strong greywacke sandstone and siltstone. The enormous size of some of the boulders indicates that their source rock was thick bedded and sparsely jointed. This is a stark contrast to the rock mass quality on the eastern side of Ramsay Glacier which is very closely jointed, and incapable of being a source of large boulders.

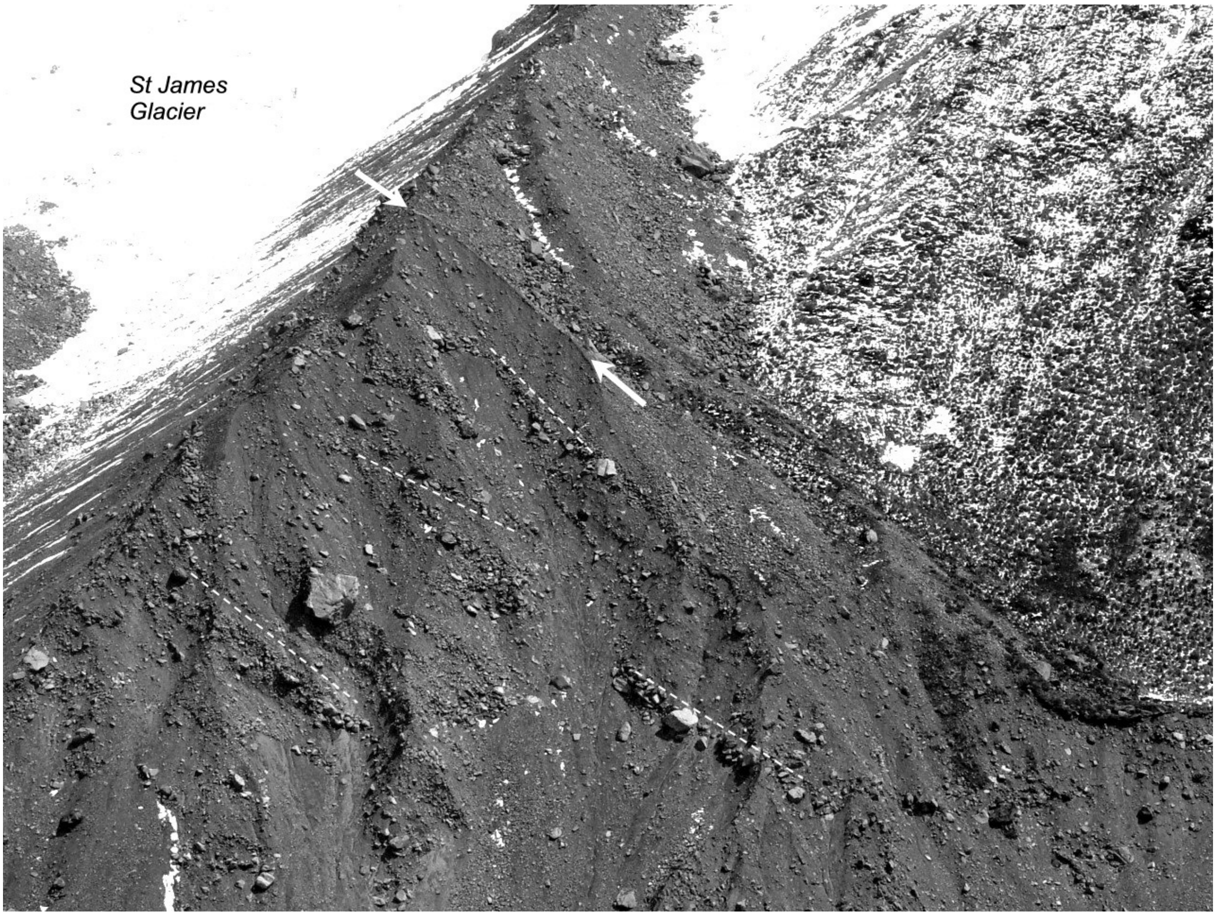


Figure 6 Closer view of the source area of the fatal rockfall (debris fall). Here dry ravelling of the loose material is sapping at the former left lateral moraine of St James Glacier. As sapping progresses, the height of the slope is increasing. The larger boulder here is about ten metres across. Note crude stratification in the deposits with bedding sub parallel to the upper surface of the glacier moraine (indicated by dotted lines). Boulders lie with their longer axes sub parallel to this bedding. The fatal rockfall came from within this view. Arrows indicate a section with apparently very sharp edges that may represent the fresh headscarp of the debris-fall zone of depletion. The "fresh" area is some 50 metres by 20 metres, representing a loss of some 5,000–10,000 cubic metres of debris. St James Glacier last stood at the crest of this moraine about the middle of the 19th century.

3.0 WEATHER CONDITIONS

3.1 General

A strong southwest airflow covered much of the country on 9 November 2002, caused by a low of 976 hPa centred several hundred kilometres southwest of South Island.

The accident site lies some 5 km southeast of the main divide of the Southern Alps, well within the zone affected by spillover of westerly rain across the divide.

3.2 Weather prior to the accident

There was rain and strong wind in the Rakaia valley on 9 November 2002, and for some days prior, but the weather was unexceptional. In order to plan their future activities, the trampers

Figure 7 The scree of large boulders where the accident occurred. The neck of the hourglass is in the upper left, and the lake edge in the lower right. Not all of these boulders fell in the debris fall (rockfall) of 9 November 2002. Note large boulders that have rolled or skipped beyond the foot of the scree. Boulders were found to 40 metres beyond the lower scree, indicating a minimum speed of 150 km/hr. Dotted lines indicate the headscarps of very recent *en masse* flows in the surface layers of the scree slope.

sought a long-range weather report. This required they make a cell-phone call, but they had no cell-phone reception where they were. They climbed to an area on the Ramsay Glacier to make their call. The forecast was for continuing similar weather. The accident occurred as they returned.

3.3 Weather at the time of the accident

Light rain fell intermittently throughout the day on 9 November, but there was nothing about the weather at the time of the accident that could have contributed directly to the instability, or to the fatality. The wet conditions of the day and previous days, however, likely contributed to the instability of the slope by wetting and weakening the sparse matrix between boulders in the moraine. This would have increased the frequency of minor collapses, and made larger collapses more likely.

Figure 8 Close view of some of the freshly fallen boulders at the lake edge. Pack is 450 mm high for scale. Note the enormous fresh impact scar on the boulder to the right of the pack, marked by a fan-shaped array of lines on a rock face, radiating away from the point of impact. (marked by arrow). See Figure 9 for close view of this fresh impact scar.

4.0 THE ROCKFALL

4.1 The witness account

The two trampers were returning from the Ramsay Glacier to Reischek Hut. Mr Hassall had only a few minutes earlier cautioned his companion to watch out for rockfalls, when a large mass of the moraine wall collapsed and bore down upon them. They rushed to escape the falling debris. Mr Duggan escaped without injury. Mr Hassall was hit by a flying boulder and knocked into the lake, receiving fatal injuries. Mr Duggan did not see the impact.

Mr Duggan retrieved the body from the lake, spent the night at Reischek Hut, and reported the fatality from Glenfalloch Station the following morning.

Figure 9 Close view of a typical scar on the fresh greywacke sandstone from the high-speed impacts of boulders during the debris fall. Some of these boulders where rolling and skipping down the scree and flew beyond the scree margins with minimum speeds of 150 km/hr. Pen is 140 mm for scale. Circle marks point of impact.

4.2 Source of the rockfall

The general bouldery gravel source of the rockfall was easily identifiable to within several hundred metres or so (Frontispiece, Fig. 6) during our visit, but the specific source scar could not be positively identified. A possible source suggested by the apparently very sharp edge to the local headscarp is indicated by the arrows on Figure 6. We could clearly recognise that the lower slope was a rockfall scree that had very recently experienced repeated rockfalls of a range of sizes. There was insufficient information to give us an accurate impression of the volume of the deposit of the fatal rockfall of 9 November 2002, but based on our estimate of the size of apparent scar at the crest (50m x 20 m and some 5 to 10 metres thick, Fig. 6), the collapse was likely to have been 5,000–10,000 cubic metres in volume. Within this debris, were many hundreds of very large boulders, greater than a metre in diameter, which were able to reach the lower slopes of the scree. We do not know how much debris went into the lake, and out of sight.

Figure 10 A cluster of fragments of a freshly fractured boulder at the foot of the rockfall scree. Pack is 450 mm high. All of these boulders are lying on alluvial gravel deposited by the stream draining from St James Glacier. Thus these boulders have travelled beyond the foot of the rockfall scree, either by rolling or leaping. To break a large fresh greywacke sandstone boulder into the myriad of fragments seen here requires an enormous amount of energy from a collision between two boulders. To reach this site requires one of them to have been travelling on a ballistic trajectory at a minimum speed of 150 km/hr. It is not known if these fragments are from the flying boulder, or from another hit by it.

4.3 Rockfall dynamics

The material that collapsed was coarse gravel with boulders in it, but most of the stones that reached the accident site were very large boulders (up to several metres across) (Fig. 7), or fragments flying from them during very high velocity collisions with other boulders. All of the finer material from the source was trapped between boulders on the upper slopes of the scree, and only the coarsest boulders reached the bottom of the slope (Fig. 8). Most of the initial collapsing debris mass consisted of much finer material, and so, this process is steepening the upper scree slopes. Collapses have been occurring for decades. Episodically, the steepening surface layers of the scree are sufficiently disturbed that they begin to flow *en masse* to lower on the slope. Evidence of recent *en masse* flows of portions of the scree surface can be seen in Figs 5 and 7.

The long-term process of collapse of the loose material of the moraine wall is called dry ravelling, but the particular collapse itself can be classified as a very rapid, dry, debris fall, and in short, a debris fall (Cruden and Varnes, 1996). This collapse, however, was on such a large scale, and with such large boulders, that it behaved exactly as would a large rockfall from bedrock, and there is little practical justification in describing it as anything but a rockfall to the public.

The boulders that fell from the moraine were of high strength, grey to dark grey, fresh greywacke sandstone. There was abundant evidence for very-high-energy impacts between boulders (Figs 8, 9). Most boulders were sharply angular and had scratches, gouges and obvious fresh fracture surfaces due to impact with other particles. Fracturing of this very hard material (Figs 9, 10) required considerable energy, indicating that individual boulders were travelling at many metres per second during the event. Many of the boulders skipped and jumped along their fall path, and the slope would have been sprayed with "shrapnel" during the 9 November rockfall. Sharply angular, freshly fractured rock fragments (Fig. 11) were found up to 40 metres beyond the foot of the slope, attesting to the high velocity of the flying rock fragments (simple calculation of their ballistic trajectories indicates a minimum speed of 42m/s [150 km/hr]). There also were several impact craters about 150 mm deep and 200-300 mm across on the alluvial fan beyond the foot of the scree, marking where large boulders had hit the fan as they bounced beyond the foot of the scree.

From the time the pair saw the rock mass collapse more than 200 metres above them, they had about 10 seconds to get out of its way in a scramble amongst boulders a metre and more across (Figs 7,8). As evidence that they were already most of their way across this area of very high risk, one of them escaped uninjured.

With an average boulder volume at the base of the scree of about one cubic metre, and density 2.7 tonnes/cubic metre, Mr Hassall may have been hit by the equivalent of a small car travelling at 150 km/hr.

5.0 CONSEQUENCES OF THE ROCKFALL

5.1 Damage to life, property and the landscape

The only significant damage caused by this rockfall was the death of Mr Hassall.

Although the rockfall fell across the route to the Ramsay Glacier, it did not destroy it, nor did it perceptibly alter the landscape.

5.2 Secondary economic impacts

Secondary economic impacts of the Ramsay Glacier rockfall are limited to the costs of body recovery, accident investigation and report writing.

If the Transit NZ value of a human life ($4M) is assumed, the economic cost of the rockfall was about $4.1M.

5.3 Research benefit

In earlier research on large rapid landslides in the Southern Alps, we (McSaveney & Davies) had seen high-speed impact structures on cobbles of Torlesse greywacke siltstone and mudstone, but were puzzled by our inability to find equivalent structures on sandstone. As can be seen in Figs 8 and 9, this is because we had been looking at too small a scale. The structures are too large to be seen on a sandstone cobble. They have to be viewed on metre-sized boulders.

6.0 DISCUSSION

6.1 Hazard awareness

It is clear from the witness report of Mr Hassall's comment about rockfall hazard that lack of awareness of the hazard did not contribute to the accident. The pair had already traversed the particular rockfall scree without incident an hour or so earlier in the day, and had almost completed their return traverse of the hazardous area before the tragedy struck. This indicates that the rockfall frequency was not so high as to be almost incessant.

It is unlikely that Mr Hassall was aware of the range of sizes of potential rockfalls, before he saw the large one collapse upon him. Had there been only one or two rocks falling, the two could possibly have dodged them, or taken shelter behind some of the large boulders that were already there. For the size of collapse that occurred, dodging or sheltering were not useful options. It is only because they already were at the outer edge of the danger zone that one survived.

6.2 Probability of the rockfall fatality

Rockfall fatalities in the Southern Alps are not rare. What is unusual about this rockfall fatality is that it occurred in such a large rockfall. Much smaller rockfalls, including those of single boulders are much more common, and it only takes one hit to cause severe or fatal injuries (the fatality of May 2000 at Otira Gorge for example). Most New Zealand rockfall fatalities are from these smaller events.

There have been no previous rockfall fatalities in the region of the terminus of Ramsay Glacier, but this is hardly surprising considering the few people who visit the area each year, and the recent origin of the route through the hazard zone (there was no rockfall hazard along this section of the route until about 20 years ago). Loss of the safe access to the upper Ramsay Glacier across the lower glacier tongue, has led climbers to traverse the dangerous foot slopes beside the growing lake.

The rockfall danger is moderate to high along some 700 metres of the present route along the lake shore, and the length of dangerous route is increasing as the lake grows larger through glacier recession. Hence the probability of a fatal accident in this area has been increasing through time. The fatality occurred at the southern end of the danger zone, where the moraine wall is highest and least stable. It therefore occurred at the site along the route where small to large rockfall are most frequent. Thus, of the sites at which it could have occurred, it occurred at the most probable site.

Were the route to traverse the opposite (east) side of the lake, future fatalities would still be possible. We heard several small rockfalls occur on that side of the valley during our short visit. The rock-mass quality there appeared to be very poor, and the weak rockmass reached to higher elevations than on the western side.

6.3 Awareness of danger

Although Mr Hassall recognised that they were in a region where they should watch out for falling rocks, the pair were unaware of how dangerous it was to traverse along the side of the lake, or that the recent rain had made it more dangerous by increasing the likelihood of a rockfall. The route wends between large boulders for some 700 metres, and there are no sections sheltered from the rockfall hazard. It cannot be traversed rapidly, and the furthest rockfall source is less than a 10-second ballistic trajectory away from the route. The only factor that saved Mr Duggan, and all of the other people who have used this route, is that the frequency of rockfalls is low enough that a fall is unlikely to occur while the route is being traversed. This low frequency was not low enough for Mr Hassall.

7.0 CONCLUSION

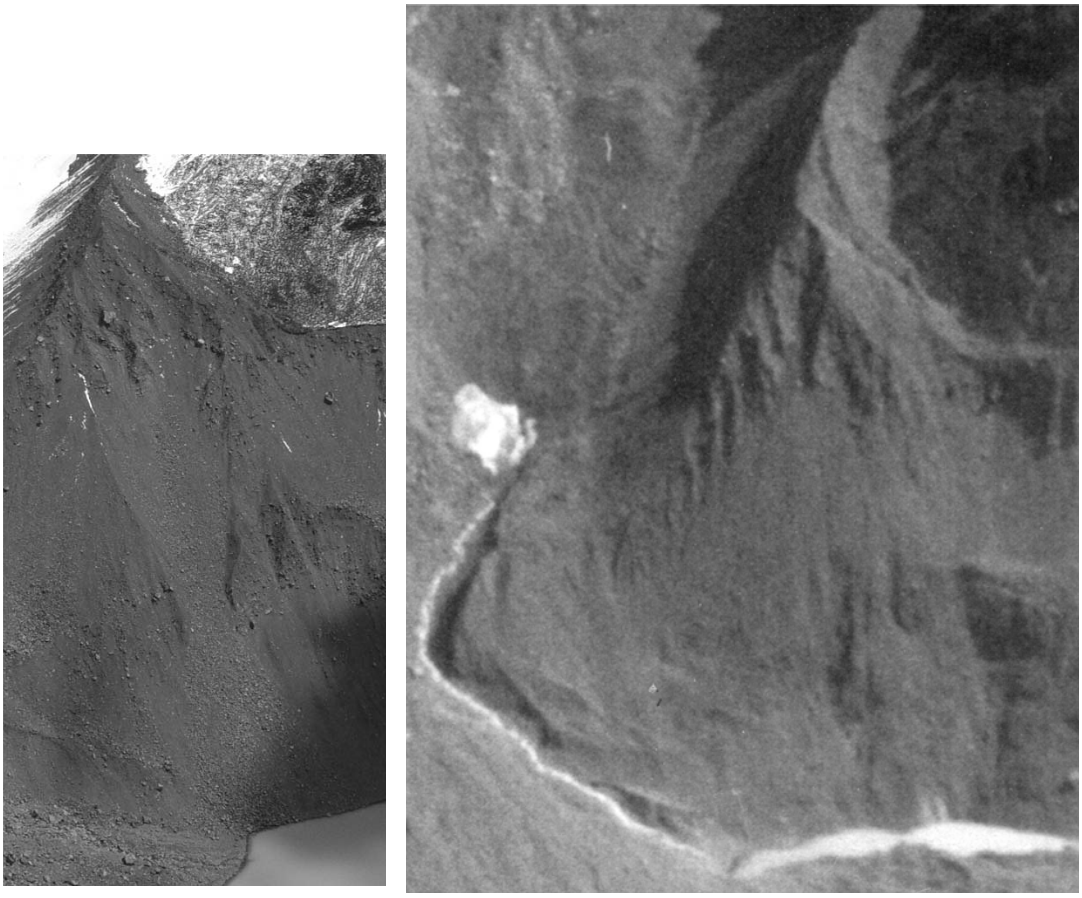
On the afternoon of 9 November 2002, Simon Raymond Hassall, 26, was killed when he was knocked into a lake by a falling boulder at Ramsay Glacier in the headwaters of Rakaia River, Canterbury. He and Mr Eric Duggan were traversing the foot of a scree beside the proglacial lake when a large rapid debris fall occurred. It fell from a 270 metre high slope of glacial moraine above them. By the time the boulder reached Mr Hassall it was probably travelling in excess of 150 km/hr. The pair had almost reached safety when Mr Hassall was struck and killed. Mr Duggan was uninjured.

The extreme danger from rockfall in this area was not known before the fatality, although the deceased recognised that there was a danger a few minutes before he was killed. The danger is at its worst during or shortly after heavy rain, and it is increasing slowly over time. The rockfall hazard along this section of the route to Ramsay Glacier has arisen through recession of the glacier, which since 1986 has cut off safe access across the glacier ice. The only feasible route now traverses some 700 metres along a series of steep screes on the western side of a lake. These screes are maintained by dry ravelling of boulders from an unstable slope of bouldery moraine that rises steeply above the lake.

In time, further glacier recession may expose a precipitous bedrock slope beside the lake, and render the route impassable. Until this occurs, users of this route face a high risk of death in further rockfalls.

8.0 REFERENCE

Cruden, D.M., & Varnes, D.J. (1996) Landslide Types and Processes, Chapter 3 *in* Landslide. Investigation and Mitigation, *Eds* Turner, A.K. and Schuster, R.L. *Special Report 247*, Transport Research Board, National Research Council, Washington D.C. p 36-75.



Endpiece Aerial views of the site of the fatal debris fall in November 2002 (left) and March 1985 (right). Earlier view is an extreme enlargement of a photograph by Trevor Chinn.

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