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A small rock avalanche in toppled schist, Lake Wanaka, New Zealand

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ABSTRACT: A rock avalanche of 100,000 m^3 occurred in a glacial valley in the Southern Alps of New Zealand in 2002. It originated on a 35° slope and released debris over a steep bluff. The resulting rock avalanche travelled 300 m, coming to rest on a gently sloping glacial bench. Individual boulders continued downslope and a number hit the Haast Pass Highway 600 m below. The bedrock in the region is mica schist, dipping at 50° into the slope. Large scale toppling is evident in the source area, with dips reduced to 20–35° in fractured, dilated rock. Aerial photos taken several years before the rock avalanche show a fresh scarp around the head, indicating significant slope deformation prior to failure. It is inferred that the scarp was the result of incipient sliding that eventually led to a catastrophic failure through loss of strength by strain weakening. The residual friction angle on the sliding surface is believed to be significantly less than the 35° slope inclination, providing conditions for rapid sliding.

1 INTRODUCTION

Large-scale mountain slope instability is widespread in the tectonically active Southern Alps of New Zealand. In schist terrain, creeping landslides and slow bedrock deformation are common. The stability of schist landslides subject to reservoir flooding was intensively studied during the Clyde Hydroelectric Dam Project, located 70 km south of the current study area (Gillon & Hancox, 1992).

Occasional rockfalls and rock avalanches occur in the schist, typically on slopes over-steepened by glacial or fluvial erosion. This study concerns a small rock avalanche of approximately 100,000 m^3 that occurred on alpine slopes above the Haast Pass Highway (SH6) on the shores of Lake Wanaka in 2002. (Figure 1) A number of boulders hit the road, resulting in temporary closure of the highway. Investigation of the rock avalanche established that the source area was a spur weakened by large-scale toppling.

The presence of widespread large-scale toppling in New Zealand alpine greywacke terrain has been previously noted (Prebble, 1992). There is less apparent recognition of similar toppling in schist, (the metamorphic equivalent) although toppling prior to a rapid rockslide-rockfall has been reported (Halliday & McKelvey, 2004).

2 GEOLOGICAL SETTING

The rock avalanche site is located in the Southern Alps 45 km east of the Alpine Fault, the boundary between the Australian and Pacific tectonic plates. Uplift of >10 mm/yr is occurring due to the oblique plate collision, and there is a high horizontal tectonic stress regime. The area is seismically active, with major earthquakes of up to Richter Magnitude 8 on the Alpine Fault every 200–300 years.

The Alps were heavily glaciated during the Pleistocene. Post-glacial ice retreat approximately 15,000 years ago left steep sided U-shaped valleys, subsequently subject to fluvial erosion.

The bedrock in the region is typically mica schist, representing metamorphosed sandstones and mudstones of Permian-Jurassic age. It is tectonically deformed with moderate to steep dips.

Extensive slow gravitational bedrock deformation and landsliding of schist debris has occurred on the steep valley sides. There is geological evidence of numerous past rapid rockslides and rock avalanches in the region, and in 2007 a large schist rock avalanche formed a landslide dam in the Young Valley, 20 km to the north.

3 GEOLOGY AND TOPOGRAPHY

The rock avalanche originated on a 35° sloping spur above the Haast Pass Highway (SH6), at Sheepskin Creek near the head of Lake Wanaka (Figures 1–3). Steep bluffs lie beneath the source area, with the slope grading out to a gently sloping glacial bench. Below the bench, steep slopes with numerous vertical bluffs extend down to the highway and lake.

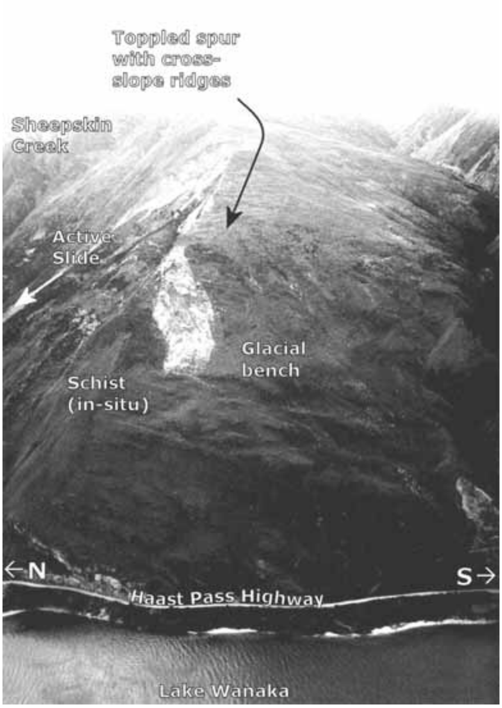

Figure 1. Rock avalanche above the Haast Pass Highway.

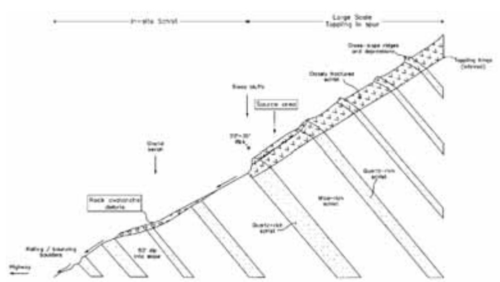

Figure 2. Cross-section of the rock avalanche area.

In situ schist outcrops below the bench and dips into the slope at an average 50° (Figures 2 & 4). The schist in the source area and further upslope towards the crest of the range is extensively disturbed by large-scale toppling, evidenced by reduced dips, fractured outcrops and "sagging" geomorphology.

A large active landslide lies over the ridge crest to the north, and sliding has also occurred on the slopes to the south.

The bedrock is composed of interlayered quartz-rich schist and mica-rich schist, and the relative

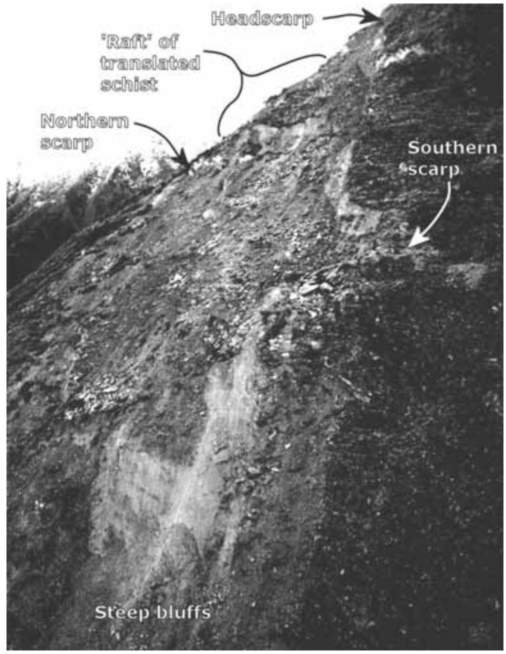

Figure 3. Rock avalanche source area, side view.

proportions of the two rock types vary in the stratigraphic column. Predominantly quartz-rich schist units form prominent escarpments, and units dominated by weaker mica-rich schist have gentler profiles.

The quartz-rich schist is typically moderately strong, and is composed of alternating laminae of quartz-feldspar and mica. Mica-rich schist is weak, well laminated and fissile, due to mica dominating over quartz-feldspar. Weathering of the rock mass is typically slight.

The schist has a pronounced anisotropy, with UCS highly dependent on foliation orientation. Previous testing of similar schist in the Clyde dam reservoir gave USC values typically ranging from 5–105 MPa (Beetham et al, 1992). A similar range of strengths are considered likely in the site area, with the mica-rich lithologies at the lower end of the range, (approximately 5–20 MPa) and the quartz-rich at the upper.

No faults or major crush zones were mapped in the rock avalanche area but foliation shears are common.

The dominant joints of Set A dip at an average 80° out of the slope and are persistent for tens of meters forming the faces of steep bluffs. (Figure 4) They are rough and moderately-widely spaced. Set B joints are sub-vertical and strike at right angles into the slope. They are rough and moderately-widely spaced.

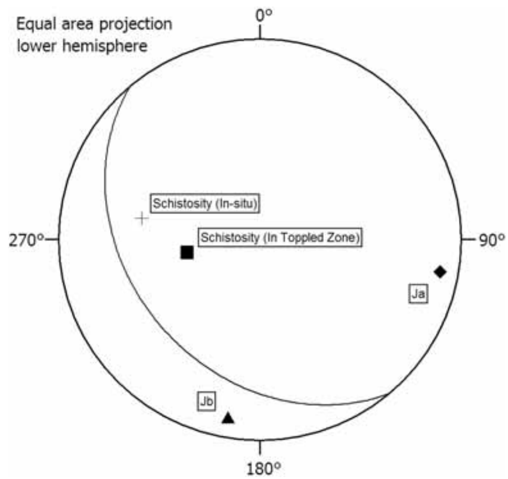

Figure 4. Lower hemisphere, polar, equal area stereoplots of mean attitudes of rock defects. The great circle indicates average dip of slope surface in the rock avalanche source area.

4 LARGE-SCALE TOPPLING

The rock avalanche source area is located on a spur exhibiting undulating cross-slope ridges and troughs, typical of 'sagging' geomorphology (Figures 1 & 3). This landform extends upslope towards the crest of the range, with ridges apparently corresponding to quartz-rich units and troughs to mica-rich units. Outcrops are fractured and dilated, and schistosity dips into the slope at 20–35° compared with 50° in undisturbed schist.

The evidence indicates that the rock in the spur has undergone large-scale toppling. Exposures in the sides of the rock avalanche source area show no obvious increase in dip to a depth of 10 m, and it is inferred that the hinge zone of the topple lies at greater depth.

Large-scale toppling in the slope is facilitated by low friction angles along micaceous foliation defects, and undercutting of the toe by glacial action. Strong seismic shaking from major earthquakes associated with the nearby plate boundary, and elevated pore-water pressures during extreme rainfall events will also have promoted the toppling process.

Flexural toppling appears the dominant mechanism in the mica-rich schist, and block-flexural or block toppling in the quartz-rich schist.

5 ROCK AVALANCHE OBSERVATIONS

The failure followed a period of rainfall, but it was not an exceptional event for the region, which is subject to frequent heavy rainfalls. There were no significant seismic events at the time of failure.

The rock avalanche was not directly observed, but a motorist driving along the Haast Pass Highway saw boulders falling onto the road and raised the alarm. Because of the risk of further rockfalls, the highway was immediately closed. Investigations were initiated to determine the source of the rockfall and the risk to the highway.

The slopes above the highway were examined by helicopter and on foot. A lobe of rock avalanche debris was visible on a glacial bench high above the road, and the travel path could be traced back to the source area on the hillside above (Figure 5). The bulk of the debris had stopped on the bench, but some boulders continued rolling and bouncing over the bluffs towards the lake, with a small proportion hitting the highway. Their routes could be traced by tracks left in the scrubby vegetation (Figure 6).

The debris volume was estimated to be of the order of 100,000 m^3. The travel distance was 300 m, but individual boulders continued a further 600 m to reach the road and lake.

Figure 5. View of the rock avalanche from the toe.

Figure 6. Traces left by rolling/bouncing boulders below the rock avalanche toe.

6 SOURCE AREA DESCRIPTION

An aerial photograph taken several years before the rock avalanche (Figure 7) shows a pre-existing fresh scarp around the head of the source area.

The rock types in the source area were closely examined after the failure (Figure 2). A prominent horizon of quartz-rich schist occupies the base, and forms the steep bluffs below. Above is a thick unit of mica-rich schist that underlies most of the failure, with a further quartz-rich unit at the head.

The evacuated source area was roughly triangular in shape and sloped at 35° (Figure 3). A scarp up to 10 m high, faced by toppled schist, extended around the head and followed the southern margin. The scarp around the northern margin was generally lower and less defined, and lay in toppled schist or schist debris.

Toppled schist exposed in the southern scarp was closely fractured and dilated along schistosity and other rock mass defects. Very rough bending fractures across schistosity were also evident.

A layer of loose schist debris covered the floor and proved difficult to traverse on foot, due to the slippery micaceous surfaces of the slabs. Only limited field work was possible due to danger from falling debris.

Of particular interest was a large semi-intact 'raft' of predominantly quartz-rich schist, still bearing vegetation, that had moved a short distance downslope from the head region. (Figure 3). A fresh scarp about 10 m high extended across the lower face. The 'raft' had clearly been displaced by translational sliding.

A small exposure of a smooth micaceous silt coated plane underlain by schist was seen on the southern lateral margin adjacent to the 'raft', and is thought to be a section of the sliding surface. An apparently similar feature was seen from the air on the northern margin.

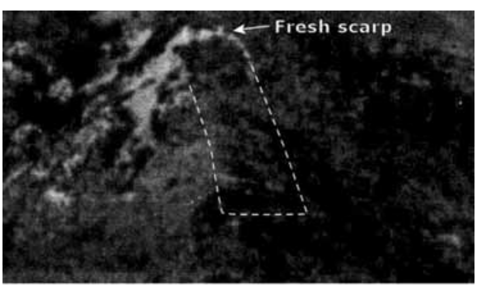

Figure 7. Source area prior to failure showing fresh scarp around head region, remaining boundary indicated.

7 FAILURE MECHANISM

The available field data, coupled with the properties of the rock mass, suggest the failure mechanism was translational sliding.

Strong evidence to support this mechanism was found at the top of the source area, where the large semi-intact raft of quartz-rich schist remaining on the slope had undergone translational sliding. Smooth rock surfaces exposed at the adjacent lateral margins appear to be sliding planes.

The remaining slope below (apart from the toe region) was underlain by weak, mica-rich schist. There was no field evidence to indicate the failure mechanism in this unit. However, studies of toppling mechanics (Nichol et al, 2002) indicate that catastrophic toppling failure is highly unlikely in such weak rock, and sliding is thus considered the probable mechanism.

The quartz-rich schist in the toe region probably failed by sliding in a similar manner to the quartz-rich unit at the head.

How the incipient slide plane developed through the toppled schist is unknown. No obvious persistent slope-parallel joints or other defect sets were detected, and the toppling hinge zone appears to lie too deep to form the failure surface. Possibly progressive failure along minor slope parallel fractures generated by the toppling process, or along stress relief surfaces, may have been involved.

Translational slides are likely to be rapid if strain weakening on the rupture surface results in a residual friction angle significantly less than the rupture surface inclination (Fell et al, 2000).

In slowly creeping schist landslides in the Cromwell Gorge, effective field strengths along failure surfaces range from 21–29° (Macfarlane et al, 1992). This range is considered indicative of residual strength values on well developed schist sliding surfaces in the region.

The residual strength on the failure surface in the predominantly mica-rich schist at Sheepskin Creek would be expected to lie at the lower end of this range ie significantly less than the slope inclination of 35°. Thus rapid translational sliding would appear possible as a result of strain weakening.

Following the main failure, a slow retrogressive slide of the quartz-rich unit at the head is thought to have occurred, translating the 'raft' a short distance downslope. Sliding may have been slower due to a higher residual friction angle in the quartz-rich schist.

The fundamental watertable in the source area appears to lie beneath the sliding plane, but infiltrating rainfall may have perched on the incipient failure surface. Elevated porewater pressure from the period of rainfall before failure was probably the final trigger of movement.

8 DISCUSSIONS AND CONCLUSIONS

The rock avalanche is thought to have resulted from a rapid sliding failure of a weakened mass of toppled schist. Rapid translational sliding is thought to have occurred as a result of strain weakening, with the residual friction angle in the weak, mica-rich schist being significantly lower than the slope inclination.

Large-scale toppling is widespread in the schist rock adjacent to the failure area and above other sections of the Haast Pass Highway, and rockfalls and rock avalanches present a hazard to the road. It may be possible to gain warning of future failures by aerial examination of the slopes for precursory scarps and tension cracks.

There is high probability of a major earthquake on the Alpine Fault in the next 50 years. It is likely to trigger widespread rock avalanching in weak rock masses such as the toppled schist, and could result in major blockages of the Haast Pass Highway.

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