Boulder weathering processes at the margins of perennial snowpatches

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1. INTRODUCTION

Previous studies (e.g. Ballantyne *et al* 1989, Thorn 1975, Berrisford 1991) have demonstrated that rock weathering is enhanced at the margins of late-lying and perennial snowpatches. However, uncertainty remains over the nature of the weathering processes involved and factors controlling spatial variability. A range of processes have been suggested including freeze-thaw shattering (Berrisford 1991), chemical weathering (Thorn 1975) and wetting and drying (Kariya 2002). This study aims to shed light on factors influencing sub-nival boulder weathering processes in an active periglacial environment.

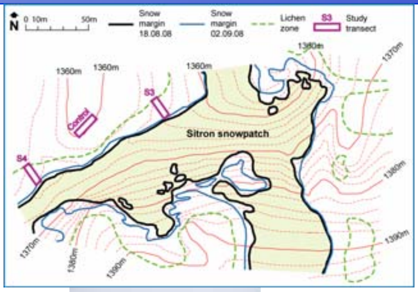
2. STUDY AREA

Work was conducted at an elevation of 1300-1600m in the Snøskar catchment (Fig. 1) in the south western sector of Hardangervidda Plateau, Norway, the largest high mountain plateau in Europe. Mean annual temperature is -2ºC and mean annual precipitation 1000mm. The catchment is in glacially eroded, high grade metamorphic basement rocks varying from meta-gabbros to granitic gneiss.

***Fig. 1:** Location of the Snøskar study area.*

3. METHODS

Two study transects and a control site were selected at two snow-patches facing NW (Sitron, Figs. 2 and 3) and E (West Ridge, Fig. 4). Total transect length was 157m (both sites) and slope gradients varied from 6 to 17º. At 2m intervals along each transect, measurements were made of weathering rind thickness (*n*=750), rock fracture (*n*=2077) and Schmidt hammer rebound (*n*=1425). Control sites were selected outside the influence of late-lying snow as indicated by dense lichen cover (Fig. 13). For this reason, the Schmidt hammer was not used at control sites. In each 1.5 x 1.5m quadrat along the transect, ten weathering rind thicknesses (WRT) were determined on blocks with a 4-12cm long axis. Measurements were made perpendicular to the stone surface and to an accuracy of ±0.5mm. Surface hardness was determined using an 'N' type Schmidt hammer. At each transect interval, one boulder with length >0.4m was selected. Five sets of five impacts were made on each boulder and the resulting values adjusted for angle. The classification developed by Berrisford (1991) was used to determine rock fracture at each transect interval. Up to 2.5m either side of the transect line, 25 clasts were selected and evidence for mechanical flaking or splitting was recorded.



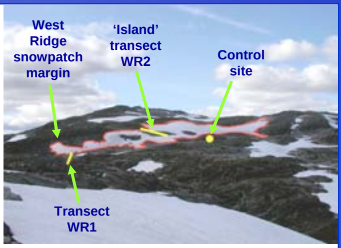


***Fig. 2** (left): Transect 3 at Sitron snowpatch.*

***Fig. 3** (above): Map of Sitron snowpatch and study transects. The snow margin was re-surveyed after 15 days. The snow core is retained through the summer in most years. The 'lichen zone' represents the area considered to remain snow-free from early spring.*

***Fig. 4** (above right): West Ridge snowpatch showing location of transects WR1, WR2 and the control site.*

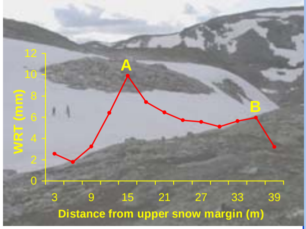
4. WEATHERING RIND THICKNESS

WRT shows a four-fold increase for snow accumulation areas compared with snow-free control sites. All transects generally show a steady reduction in WRT with increasing distance from the snowpatch margins. Mean WRT values vary at WR1 from 1.2 to 7.6mm and at S3 from 3.5 to 8.4mm. WRT at control sites varies from 0.7 to 1.7mm and 0.7 to 1.4mm respectively. Values are broadly comparable with those of Hall (1993) for snow-free sites (1.57mm) and snow accumulation sites (4.34mm). Observations suggest that deviations from the general rule reflect local variation in topography or slope processes. For example, transect WR2 represents an 'island' in the late-lying snow cover. Close to its upper snow margin (**A** in Fig. 5) WRT is very low but this area corresponds with obvious visual disturbance of the boulders due to colluvial inputs from a steep

4. WEATHERING RIND THICKNESS CONT'D

slope above. Thus boulders may be moved around and preclude rind development, or else rind may be eroded. Near the lower snow margin of WR2 there is an anomalous peak in WRT (**B** in Fig. 5). This corresponds with a topographic hollow where moisture collects and may lead to locally enhanced weathering. A similar peak in WRT occurs at the upper, snow-free end of S4, and coincides with a solifluction lobe (Fig. 14). This concentrates moisture supply, again, leading to enhanced weathering.

***Fig. 5:** WRT for transect WR2 with its 'island' form seen in the background image.*

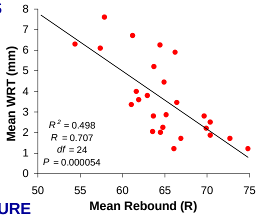


5. SURFACE HARDNESS

For surface hardness, three of the four transects (WR1, S3 and S4) show an inverse relationship to the pattern for WRT. Since sub-nival weathering is thought to enhance rock breakdown, this result is as expected. Indeed, there is a statistically significant correlation between Schmidt hammer rebound and WRT (Fig. 6). The close correlation of surface hardness with WRT suggests that chemical weathering may prevail (Hall 1993). However, surface hardness is partially dependent on rock porosity (Nicholson 2008) and the findings may indicate micro-mechanical processes (Nicholson 2009) that result in an increase in porosity. Along transect WR2 there are some large fluctuations in surface hardness. At its upper margin, a thin, shallow strip of snow commonly persists into August and yet surface hardness is high (68-72). This may reflect the input of fresh material from fractured bedrock upslope (Fig. 9). Further down the transect, high surface

5. SURFACE HARDNESS CONT'D

hardness values (67-68) occur where the boulder field forms a steep bank leading down to the lower snow margin. Minimal surface weathering here suggests snow cover does not persist late into the season because of the steep relief.

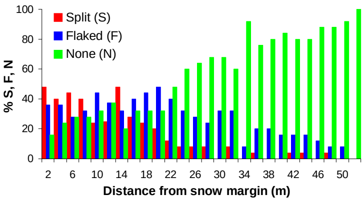


6. MECHANICAL FRACTURE

Boulder fracture shows a three to four-fold increase for areas within the snow cover margin compared with control sites. At control sites, 87% of clasts show *no* surficial fracturing compared with 55% for all other transects. At sites WR and S an average of 16% of blocks are split and 29% have surficial fractures (Fig. 10). There is no appreciable difference between transects at the two snowpatches. However, at each transect, the proportion of split or fractured blocks decreases with distance from the snow margin (Figs. 7 and 8). There is some suggestion with S3 and WR1

***Fig. 6** (above): WRT and surface hardness correlation.*

***Fig. 7** (right): Rock fracture, West Ridge transect WR1.*



6. MECHANICAL FRACTURE CONT'D

of a distinct reduction in mechanical damage about equi-distance along the transects. This may indicate the average boundary of the snow margin, with snow only extending beyond this in some years. Processes responsible for boulder fracture are inconclusive. Short term fluctuations across 0ºC leading to freeze-thaw are unlikely to be important because of the insulating effect of snow cover (Hall 1993). Berrisford (1991) has argued for long duration freezing with water migration (after Walder and Hallett 1985). Kariya (2002) makes a case for the role of wetting and drying in debris production beneath snow. However, the observed coincidence between decreasing WRT and boulder fracture and increasing surface hardness with distance from the snow margin (Figs. 11 and 12) suggests a single controlling factor. This is despite the apparent contrast in mechanisms responsible for each of these properties (i.e. chemical and mechanical processes). Moisture supply appears to be the likeliest explanation.

***Fig. 8** (right): Rock fracture patterns, Sitron transect S3.*

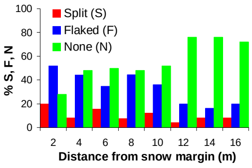


***Fig. 9** (below): Evidence of damage from impact and downslope movement.*

***Fig. 10** (right): A split boulder indicated by fresh face intersecting weathering rind.*

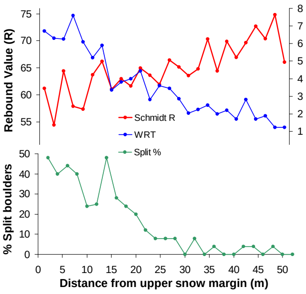


***Fig. 11** (left): Surface hardness, rock fracture and WRT with increasing distance from the snow margin at transect WR1.*

***Fig. 12** (below left): Surface hardness, rock fracture and WRT with increasing distance from the snow margin at transect S3. Despite the measurements being indicative of very different weathering mechanisms, these data suggest a common fundamental controlling factor.*

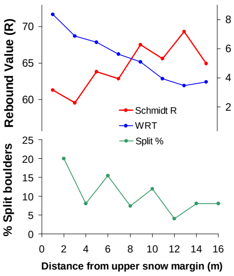
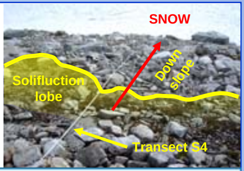
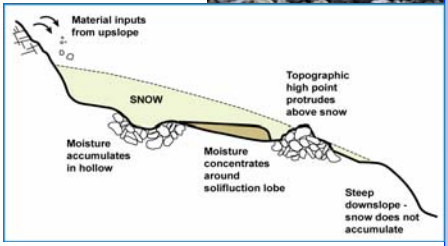


***Fig. 13** (below): In the vicinity of the control site at Sitron snowpatch. Note the obvious lichen and vegetation-free area on the raised ground adjacent to the snowpatch margin.*

***Fig. 14** (right): Looking down study transect S4 at Sitron. Note the solifluction lobe that probably provides a local source of additional moisture.*

***Fig. 15** (below): Diagrammatic representation of factors influencing the spatial variability of sub-nival weathering.*





7. CONCLUSIONS AND FURTHER WORK

The study verifies both the role of snow-cover in enhancing rock weathering and the importance of chemical weathering in cold environments. However, both chemical and mechanical processes are invoked at a variety of scales. There is considerable benefit in employing multiple indices that highlight different weathering products. Moisture availability may be the primary control on weathering intensity, but other factors control local spatial variability including micro-topography and downslope movement of sediment (Figs. 9, 13 and 15). There remains much work to be done to elucidate the role of biological agents and lithological control on sub-nival weathering.

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