ARTICLES AND NOTES

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THE HYDROLOGIC SIGNIFICANCE OF NIVATION FEATURES IN PERMAFROST AREAS

Abstract

Many accounts of nivation activity stress the role of snowpatches in supplying water to the area immediately downslope, thereby facilitating extensive rillwash and solifluction. It is often assumed that melt of the snowpatch itself provides the main source of water. Runoff measurements and dye-tracing observations carried out on perennial snowpatches in the Canadian Arctic indicate that the main source of runoff in nivation features is active layer interflow, brought to the surface by the absence of a thawed zone beneath snowpatches.

INTRODUCTION

Many writers on the topic of nivation have commented on the geomorphic importance of meltwater issuing from the downslope margins of perennial and late-lying snowpatches. Some authors (e.g. LEWIS, 1939; WILKINSON and BUNTING, 1975) have emphasized the role of nival meltwater as a transportation agent in the form of rillwash or sheetwash. Others, such as BOTCH (1946), WILLIAMS (1957), and COOK and RAICHE (1962) have described the main effect of nival meltwater as the saturation of the regolith downslope from snowpatches, with intense solifluction activity resulting. ST. ONGE (1969) reconciled these viewpoints in a study of nivation features on Ellef Rignes Island in the Canadian Arctic Archipelago. He considered that the relative dominance of wash or solifluction was determined by the granulometric characteristics of the regolith, rillwash or sheetwash being dominant where rock breakdown has produced particles of silt or fine sand size.

Much less attention has been focussed on the sources of the water which emanates from the lower margins of snowpatches to cause such activity. LEWIS (1939) suggested that melting snow formed the primary source of moisture. In their study of rillwash in the Canadian High Arctic, WILKINSON and BUNTING (1975) described interflow from talus slopes rising above snowpatches as being a significant source, but considered that snowmelt achieved greater quantitative importance as the arctic summer progressed. However, during observations made on nivation hollows and benches on Ellesmere Island, in the Canadian Arctic Archipelago,

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it became apparent that neither explanation was entirely adequate to account for the considerable volumes of water which were seen to drain from small snowpatches. This note describes preliminary investigations into the sources of water draining from perennial and semi-permanent snowpatches in this area.

SNOWPATCHES AND NIVATION LANDFORMS IN THE STUDY AREA

The nivation features under discussion are located near the head of Vendom Fiord, Ellesmere Island, N.W.T., Canada (78°02′N; 82°05′W). They are found mainly on north-facing and west-facing slopes immediately below the crest of a broad ridge at an altitude of approximately 500 m. The underlying bedrock consists of dolomites and sandy limestones of Silurian age (NORRIS, 1963), mantled to variable depths by locally derived coarse weathered debris and patches of glacial till. All of the observed nivation features were developed on this coarse regolith; in no instance did bedrock outcrop within a snow-free nivation feature or adjacent to a snowpatch.

Nivation benches supporting "transverse" snowpatches (LEWIS, 1939) are common in this area, but true nivation hollows (scooped-out forms containing "circular" snowpatches) are also found. The features were examined in late July and early August, 1975, when the size of perennial and semi-permanent snowpatches was at its minimum for the year and when late-lying snowpatches had completely melted. At this time the across-slope dimensions of transverse snowpatches ranged from 4 m to 110 m. Circular snowpatches were smaller, the largest not exceeding 40 m in diameter. All perennial "snowpatches" consisted substantially of ice (density > 0.8 g cm^{-3}) with overlying patches of granular snow and firn (density $0.4-0.6$ g cm^{-3}). The former is interpreted as perennial, and the latter are probably remnants from the previous winter's snowfall. The basal layers of ice often contained dark debris-rich layers, similar to those described at the base of high-latitude snowpatches by MCCABE (1939) and WILKINSON and BUNTING (1975). The sources of this fine material include the slushflows and mudslumps which were observed on the surfaces of several snowpatches as well as windblown matter. Two of the largest observed snowpatches were crevassed below their upslope margins, indicating that some snowpatch movement had taken place.

All of the observed nivation features had a number of common cross-sectional characteristics. The disappearance of late-lying snowpatches allowed the floors of some nivation hollows and the treads of some nivation benches to be examined. In every case the floor of tread met the base of the backwall at a sharp break of slope. Above this break of slope the generally concave backwalls rose from an initial angle of around 30° (Fig. 1).

Below the break of slope platforms with angles of less than 6° constituted the floors of nivation hollows and the treads of nivation benches. No evidence of intensive local frost action or solifluction was observed in the vicinity of the nivation features. However, intensive rillwash was evident

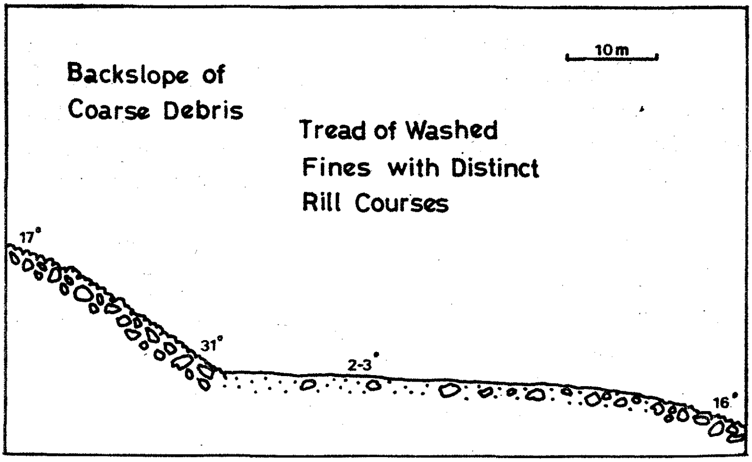

Fig. 1. Section through a snow-free nivation bench, showing the abrupt break of slope at the backslope

downslope of all surviving snowpatches (Pl. 1) even when air temperatures were less than 3°C. The visible source of these rills was always the lower margins of the snowpatches; runoff over the surfaces of snowpatches was not observed.

RUNOFF MEASUREMENTS AND THE CONTRIBUTION OF ACTIVE LAYER INTERFLOW

On July 28, 1975, crude discharge measurements were made on the runoff downslope from a small transverse snowpath by timing the filling of a one litre bottle at a point below the snowpatch where all the rills joined to form a small stream. The bottle filled in just under 5 seconds, indicating a discharge of around 7 m^3h^{-1}. This snowpatch was 19 m in length and 8 m in width. The surface slope of the snowpatch was 15°. Assuming a sub-snow profile similar to that illustrated in figure 1, the mean depth of the snowpatch would not exceed 1.5 m and its total volume would by roughly 200 m^3. If the melting of this snowpatch was providing the principal source of water runoff, then it would be expected that the snowpatch would disappear in 3 – 4 days, even allowing for a substantial decline in discharge at night. However, when the same snowpatch was revisited on August 8, 1975, it was found that its dimensions were unchanged, even though measured runoff was greater (9 m^3h^{-1}). Although snow had fallen in the interim, all recent snow has melted by August 8, so the anomaly cannot be explained by snow accumulation. It is clear that interflow from the surrounding active layer provided a very large part of the runoff from the lower margin of the snowpatch.

To test this conclusion, dye tracing techniques were employed at a different transverse snowpatch. This second snowpatch had a length of 50 m, a maximum width (downslope) of 40 m and a midpoint width of 22.5 m. Most of the snowpatch consisted of clean ice with a density of 0.84 g cm^{-3}, with overlying patches of firn with density 0.58 g cm^{-3}. The depth of the permafrost table was measured by auger along a transect, both above and below the snowpatch (Fig. 2). Although the hardness of

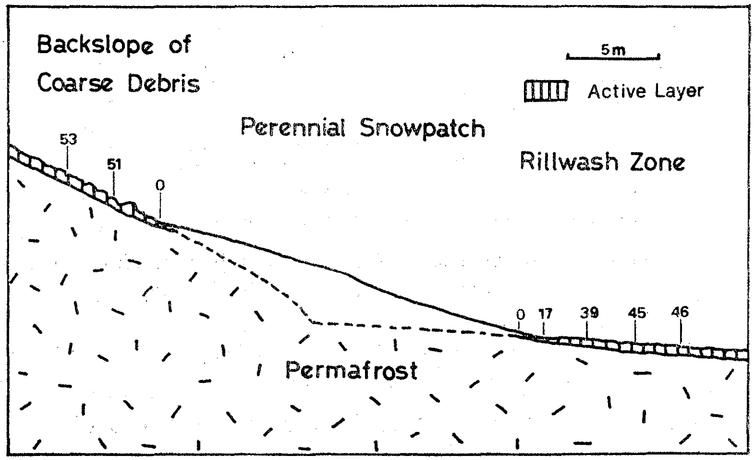

Fig. 2. Section through ice nivation bench and snowpatch at which the dye tracing was carried out
The figures refer to depth of active layer in centimeters

the ice made augering impossible on the snowpatch itself, pits cut at the upper and lower margins of the snowpatch on the line of the transect clearly indicated that beneath the snowpatch the permafrost table was at the ground surface. A similar situation has been described by McCabe (1939) for a snowpatch in Spitzbergen.

200 ml of 10% Rhodamine WT dye was poured into the regolith 5 m above the top of the snowpatch at its widest point. Two minutes after injection, dye appeared staining the snow surface near the top of the snowpatch. The dye stain progressed steadily down the snowpatch with little lateral movement, reaching the base of the snowpatch after 43 minutes, a mean percolation rate of 1.6–1.7 cm s^{-1}. On reaching the base of the snowpatch (Pl. 2) the dye was carried rapidly downslope by two small rills for 104 m, beyond which the rill water infiltrated the coarse regolith and surface flow ceased.

A cutting made in the stained ice indicated that the depth of staining extended to at least 40 cm and possibly to the base of the snowpatch, showing that percolation of interflow water was not confined to the surface layers of the ice. The permeability of the ice at depth was confirmed by injecting a small amount of dye into a shallow hole in the ice surface. The resulting stain extended from the basal layers of the ice to the surface.

DISCUSSION

The observations reported above allow a number of conclusions to be drawn concerning the hydrologic role of perennial and late-lying snowpatches in permafrost areas.

(1) Interflow from the neighbouring active layer plays a dominant role in sustaining runoff from the lower margins of snowpatches. The relative quantitative importance of melting snow or firn on the snowpatches itself is small, at least in the later part of the arctic summer.

(2) Perennial "snow" occupying nivation hollows and benches in high arctic areas consists in fact of ice with overlying firn. The evidence of percolating dye suggests that this ice is at pressure melting point.

(3) Beneath perennial snowpatches the permafrost table extends to the ground surface. This property of perennial snowpatches is crucial in bringing interflow water to the surface, thus initiating rillwash and causing saturation of the ground downslope of arctic nivation features.

The implications of this last conclusion are particularly significant. As the interflow from the active layer upslope of a snowpatch is brough to the surface at its lower margin, perennial and late-lying snowpatchet below which permafrost rises to the ground surface may be regarded as having a "catchment" much greater in area than the area of the snows bank itself. For example, the snowpatch on which the dye tracing investigations were carried out had an estimated surface area of 1,400 m^2; th- estimated "catchment" for this snowpatch was about 29,000 m^2 in areae Within this catchment various sources of water, such as melting snow. melting ice and rainfall, percolate into the active layer and contribute, to the interflow which is brought to the surface at the snowpatch. Hence the quantitative importance of the interflow water from the snowpatch "catchment" is much greater than that of water supplied by the snowpatch itself. It follows that the intensive rill action and ground saturation noted by many authors as occurring downslope from snowpatches is not necessarily the result of the melt of the snowpatch, as has often been assumed, but in permafrost areas at least results primarily from the function of snowpatches as surface runoff outlets for interflow water in the active layer.

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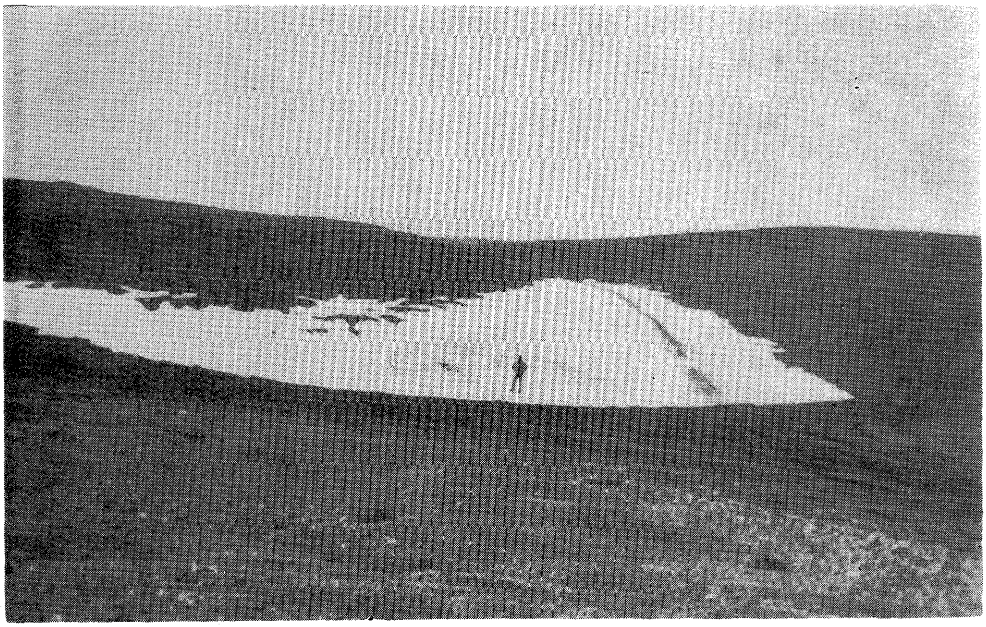
Pl. 1. The rillwash zone below a perennial snowpatch. The pattern of rilling is emphasised by the growth of dark brown mosses in the rill channels



Pl. 2. Site of the dye tracing investigations. The dye trace is the dark stain to the left of the figure