A large rock avalanche onto Morsarjökull glacier, south-east Iceland. Its implications for ice-surface evolution and glacier dynamics

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A LARGE ROCK AVALANCHE ONTO MORSÁRJÖKULL GLACIER, SOUTH-EAST ICELAND. ITS IMPLICATIONS FOR ICE-SURFACE EVOLUTION AND GLACIER DYNAMICS

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Abstract

In spring 2007, a large rock avalanche descended onto the Morsárjökull valley glacier in southeast Iceland, leaving one fifth of the glacier buried. The insulating effect of the deposit on the ice was quickly observed as a difference in the ablation between the exposed ice and that under the deposit. After three melt seasons, the ice surface under the deposit was 29 m above the surrounding glacier surface. A reduced rate of ice melting beneath the area of the deposit would likely alter the longitudinal profile of the glacier.

Introduction

Mass movements from oversteepened mountain slopes adjacent to glaciers are a common source of debris on ice surface (Benn and Evans, 1998; Hambrey and Alean, 2004), resulting from paraglacial adjustment of rock slopes (Ballantyne, 2002). Spectacular examples of large-scale rock avalanches falling onto glaciers are documented in the literature, mainly from Alaska, United States, the Himalaya and New Zealand. A characteristic of such rock avalanches is the exceptionally long distances reached by the deposits on the ice surface. On March 20 2007, a large avalanche of rock covered the valley glacier Morsárjökull, in southeast Iceland. About one fifth of the glacier surface was then buried by about 4×10^6 m^3 of debris covering an area of over 720,000 m^2. It corresponds to one third of the eastern part of the glacier. Among the questions that arose after this event are: how will the debris mass affect the movement of the glacier and how will the glacier incorporate and/or distribute the debris mass? The purpose of this study is to evaluate the effects of the rock avalanche insulation on the future morphology and movement of the glacier, based on the 3-melting season observations and measurements, but also based on a review of previous case studies.

The Morsárjökull case study

Yearly measurements of the glacier front since 1933 indicate a total retreat of over 1300 m, although small advances have also occurred during that time (Sigurðsson, 2007). As the glacier front retreats the glacier becomes thinner and narrower in its basin, and the surrounding steep slopes become more unstable. The bedrock is palagonite and pillow breccia, interlain by basaltic lava flows and cut by faults and numerous thin dykes. The scar from the rock avalanche is located on the north face of the headwall that dominates the ice fall area of the eastern Morsárjökull glacier, between 720 m and 1120 m a.s.l. A part of the northwest facing slope, 400 m high and 500 m long, collapsed onto the glacier, partially burying the medial moraine. The material then flowed southwest onto the eastern section of the glacier, reaching a horizontal length of 1400 m and a maximum drop of 660 m, for a friction coefficient of 0.47. The deposit fell onto the glacier at approximately 760 m and its lower part was located by 460 m a.s.l., over a length of 1700 m. On July 2007 the upper margin of the debris mass was located approximately 3513 m from the glacier snout and the lower margin approximately 2050 m. The contact between the ice and the deposit was sharp, and no deformation of the glacier ice was visible at the contact with the deposit or in the close surroundings, indicating a rapid process.
Photogrammetric studies of the source-area estimates the volume of the rock avalanche to be 4×10^6 m^3. Analyses of available aerial photographs show that the largest clast sizes are found in the peripheries of the deposit. The central part consists of smaller clasts. The deposit thickness is also highly variable. It changes from 1.5 to 3 m at the front to over 7 m elsewhere.

The rock avalanche deposit is located within the mid ablation zone of the glacier. Since the debris cover insulates the glacier ice from solar radiation, differential melting occurred on the surface. At the front, the deposit standed 10 m above the exposed glacier surface in early July 2007, as measured on the field with an inclinometer, 22 m in early August 2008, and 29 m in early August 2009. This caused local collapses of boulders on the boundaries of the deposit. This process contributes to widen the size of the deposit, increasing the buried surface of the glacier. According to measurements made on Skeiðarár jökull (Icelandic Meteorological Office, unpublished information), the ablation rate of Morsárjökull glacier can be estimated to 8-10 m.a^{-1}. This seems to be in accordance with the non-ablated ice under the deposit after the two melting seasons during the summers 2007, 2008 and 2009. From 07/2007 to 08/2009, the front of the debris mass progressed down glacier to a distance of about 200 m.

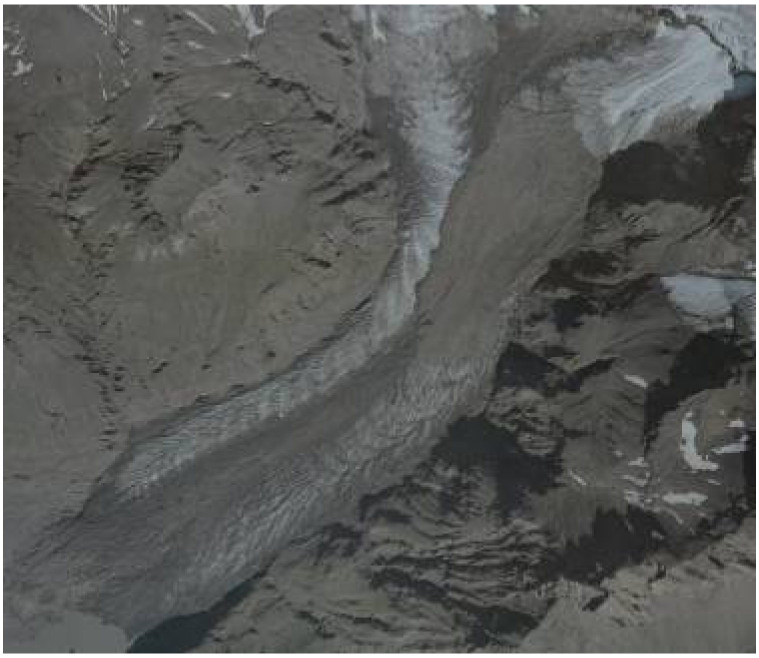

Fig. 1: The Morsarjökull glacier partially buried under the rock avalanche deposit.

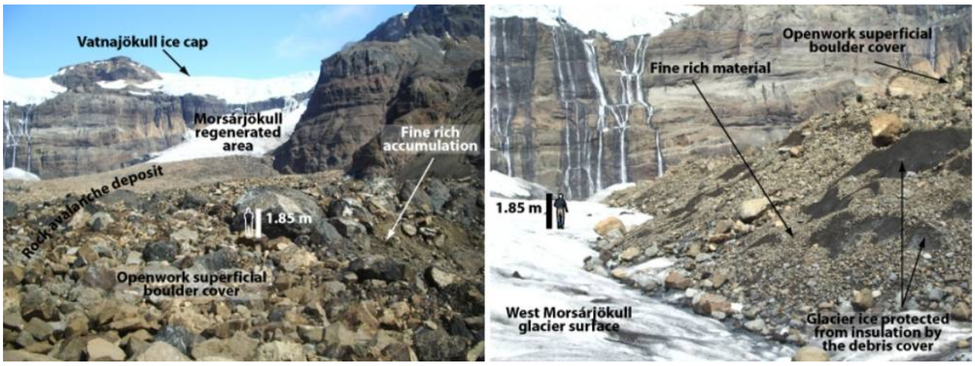

Fig. 2: The variety of material size constituting the rock avalanche deposit: clast supported on the upper layer, the deposit is enriched in fine material (gravel to coarse sand) at the contact with ice. Observers as scale are outlined on the photographs, providing scales.

Discussion on the future implications of the avalanche deposit onto the Morsárjökull glacier

According to previous case studies of rock avalanche that have fallen onto glaciers, the glaciers reacted in several ways after a part of the ice had been buried. From 1920 to 1942, the Brenva glacier in the Italian Alps encountered an advance prolongation up to *c.* 600 m following a rock avalanche that occurred in 1920. Its thickness relatively increased at the snout and farther up-glacier, while the surrounding glaciers retreated about 65 m during the same period (Deline, 2002). The Bualtar glacier in the Karakoram Range in Pakistan surged after three huge landslides partly buried the ablation zone and affected the under-glacial drainage (Gardner and Hewitt, 1990). The Sioux glacier (Alaska) experienced a significant ice thickness increase after a third of the lower part of the glacier was insulated by the debris cover. An ice mass transfer that lowered the upper unburied part of the glacier and raised the insulated lower one (Reid, 1969) resulted in an advance of the glacier snout.

Historically, two rock avalanches onto glaciers are known from southern Iceland. The rockslide that covered the terminus of the Jökulsárgilsjökull outlet glacier (south Mýrdalsjökull ice cap) in 1972 or 1973 caused substantial differential melting and the glacier snout underwent significant thickening (Sigurðsson and Williams, 1991). Part of the snout of the Steinsholtsjökull glacier, an outlet of the north Eyjafjallajökull ice cap, was covered by a 15 x 10^6 m^3 rockslide in January 1967 (Kjartansson, 1968). The rock avalanche also impacted a proglacial lake, causing a flood that flowed 35 km to the sea.

From these case studies, we underline that the effects of a rock avalanche affecting a glacier are a function of the magnitude of the event *versus* the size of the glacier, i.e. the surface and thickness of the debris cover *versus* the ice surface and thickness. Another important factor is the location of the deposit on the glacier body.

In the Morsárjökull case study, the deposit covers the mid ablation area and the snout of the glacier is mostly free of debris. Though, changes were observed soon after the rock avalanche occurred. The most obvious implication of the deposit on the glacier is the effectiveness of its insulation property on the buried ice, significantly decreasing its melting rate. Presumably, the ice that is not ablated from under the deposit will sooner or later favour an ice transfer down-glacier, as observed in other cases (Reid, 1969). The result will then be to speed down the retreat and thinning of the glacier.

The incorporation of the rocky material within the glacier should also be considered. A first possibility is that the material will be buried by snow and ice; the rock avalanche material is very coarse so it will require an abundant supply of ice and snow to be buried. This seems unlikely as the deposit is located within the ablation zone of the glacier. Nevertheless, the location of the head of the deposit in the free-falling ice avalanches part of the glacier caused the uppermost one fifth of the deposit to be buried within a thick apron of ice and snow by falling snow and ice avalanches after only 3 months. The ice apron progresses over the deposit with time. Another possibility is that the material could be incorporated into the ice by falling down crevasses in the glacier surface. As the deposit covers a part of the glacier with a poor crevasse network, it makes unlikely the incorporation of the debris into the glacier as englacial sediment. Therefore, the main part of the deposit will remain supraglacial.

From a supraglacial hydrological point of view, a few minor changes can be expected, mainly involving the western part of the Morsárjökull glacier. On the eastern side of the glacier, the deposit buried an area of relatively low channel network. On the western side, the deposit obstructs the entry of melt water into the medial moraine. Depending on the crevasse network in the western area, the drainage of supraglacial meltwater into the glacier will occur further up on the glacier.

We then assume that the main effect of the debris cover on the eastern part of the Morsárjökull glacier will be a significant reduction of the ablation along with enhanced ice transfer due to the formation of steep ice slopes and overburden pressure under the deposit. This could create an asymmetry between the two parts of the glacier: the eastern one having a less negative mass balance than the western one.

Conclusion

The collapse of the rock slope that caused the rock avalanche on the Morsárjökull glacier is a major event in the Icelandic glacial environment. Such events are rare onto glaciers. Several implications of the deposit onto the glacier can be emphasized. The part affected by the deposit is located within the ablation zone, so its impact on ice dynamics is immediate. The lower melting rate beneath the deposit is evident by a relative rise in comparison with the exposed ice reaching 29 m after 29 months. As a result, the ice surface will pursue to steepen, increasing the driving stresses and causing the down-glacier region to advance. The Morsárjökull glacier is not known as debris-mantled. Except for the present event, neither major rockfall nor rock avalanche has been recorded in the past. The present debris input to the ice surface, though large, will therefore not have a long-lasting effect, contrary to the case of the Brenva glacier which involved repeated rockfall and rock avalanches for several centuries. The debris cover onto the Morsárjökull glacier may reduce the retreat of its eastern part while its western part will probably not be similarly affected, leading to an asymmetrical front position in the future. However, the Morsárjökull glacier is presently within a retreat phase that has lasted for at least eight decades. Further slope destabilisation is therefore possible.

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