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The Editor,
Journal of Glaciology

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Supraglacial sediment accumulations and large englacial water conduits at high elevations in Mýrdalsjökull, Iceland

A number of large ice-cored sediment accumulations are present on the surface of Kötlujökull (also called Höfðabrekkujökull), a 9 km wide southeasterly outlet glacier of Mýrdalsjökull, the fourth largest ice cap in Iceland (Figs 1 and 2). The largest of the sediment accumulations is a ridge, more than 1 km long and some 100 m wide, which was located 1.5 km from the glacier terminus in 1960 (Krüger, 1994). In August 1994, the ridge had almost reached the terminus (Fig. 1c). According to our observations, the supraglacial sediments consist of basically non-striated rounded boulders, gravel and sand. Silt and clay fractions are missing. The approximately 2–3 m thick sediment cover contains a mixture of rock types. The roundness of the material, and the absence of finer fractions, make it similar to esker material. From observations in terminal crevasses and streams, Krüger (1994) found evidence for debris-loaded thrust-planes being responsible for till deposits on the margin of Kötlujökull. However, when explaining the origin of the described ice-cored sediment ridges higher up on the glacier, Krüger (1994, p. 118) likewise states

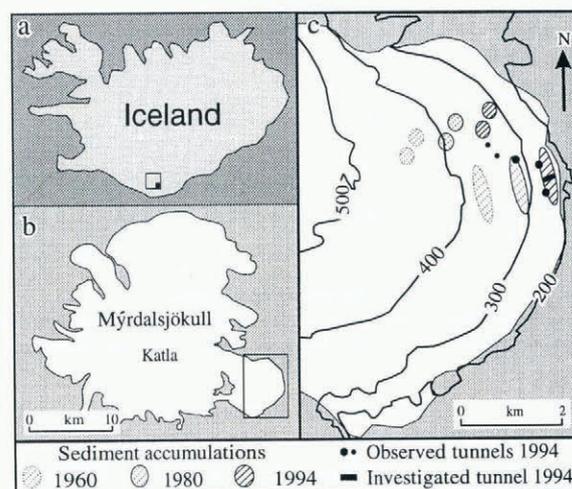


Fig. 1. Location map for the Kötlujökull outlet glacier, showing positions of supraglacial sediment accumulations in different years, and large englacial water conduits as observed in 1994. Black circles denote conduit openings, while the black rectangle shows the location of the conduit section which was investigated in more detail (see Fig. 3). The locations of conduits and sediments are approximate. During the study, only the northeastern part of the outlet glacier was visited. The large conduits shown in Figure 1c are therefore not the result of a complete inventory. A thorough mapping of the conduits would most probably increase their number.



Fig. 2. Ice-cored sediment accumulation on the Kötlujökull glacier. The glacier surface around the sediments has an extensive cover of dark volcanic ash. The lighter-coloured sediment covered hill has a height of about 15–20 m, formed by reduced ablation under the protective sediment cover compared to surrounding areas. The sediment accumulation depicted is much smaller than the largest accumulation on the glacier. Note the size of the boulders at the base of the accumulation.

that “the ridges are covered by diamict, light greyish-brown in colour, derived from steeply dipping inglacial thrust-planes”. An alternative explanation for the formation of these sediment accumulations is presented here, involving englacial fluvial-sediment transport at high elevations within the glacier.

Ablation has exposed large fossil englacial meltwater conduits, with circular cross-sections, at the same location as the sediment accumulations on the surface of Kötlujökull (Fig. 1c). Four large tunnels and several smaller ones were observed on the glacier front over a distance of a few kilometers. The conduits were located 100 m and more above the proglacial sandur. The largest conduit observed had a diameter of 12–15 m (Fig. 3), and was exposed along a length of 40 m; higher up, the tunnel had collapsed due to glacier surface ablation. Assuming that it was also initially circular, the cross-sectional shape of the conduit is unaffected by ice deformation. This

indicates that this part of the conduit system does not originate from the basal parts of the glacier. The tunnel is located in clean ice and in ice containing volcanic ash. The inner walls of the conduit were affected by ablation, as seen by the occurrence of ablation hollows. Although this ablation has increased the tunnel diameter, the conduit was probably of a great size also when it was formed and actively drained meltwater.

There is a close spatial relationship between the large englacial water conduits and the large amounts of rounded sediments found on the glacier surface. We suggest that the sediments were transported by exceptional amounts of englacial water at high elevations within the glacier in the englacial conduit system, parts of which are being exposed today. During such a process, transported material may become rounded and depleted of fines. Subsequently, sediments were ejected on to the glacier surface or were deposited englacially within the

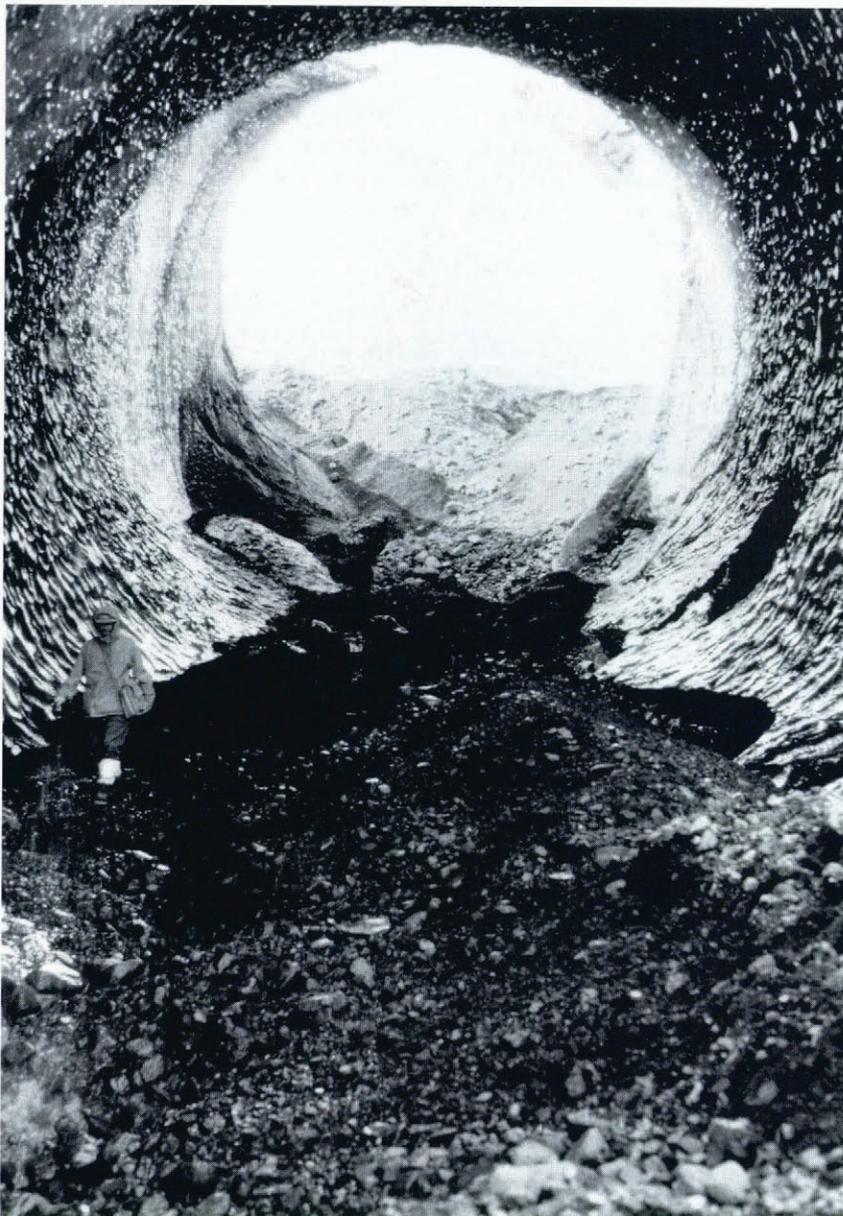


Fig. 3. Up-glacier view of the largest meltwater conduit observed on Kötlujökull, having a diameter of 12–15 m (see person to the left for scale). The collapsed section of the tunnel is seen at some distance, and some of the sediments of the largest ice-cored ridge in the background. Sediments that were probably once transported within this englacial drainage system are now found as an esker-shaped accumulation on the conduit floor. Many of the boulders inside the conduit are large, indicating that they were not transported there by surface meltwater after the collapse of the tunnel.

conduits, or both. An esker-shaped sediment accumulation can be seen on the floor of the largest investigated conduit (Fig. 3). This is a firm indication that sediments were transported within this system when it was active. A similar sediment accumulation was also found on the floor of a smaller conduit (diameter 3–4 m).

Krüger's (1994) conclusion that the sediments are of subglacial origin is probably correct. However, it is unlikely that they have been transported up to the glacier surface by thrusting of ice, or that they originate from the bed underneath the glacier front. It seems more likely that the material originates from the bed up-glacier, and that it has been transported down-glacier by englacial meltwater.

One argument for the idea of up-thrusting is that the sediment ridges run parallel to the glacier margin (Krüger 1994, p. 168). This argument refers to the largest sediment accumulation, located close to the front in 1994. However, there are other possible ways of obtaining this ridge orientation. A combined sediment deposition by several parallel water conduits close to each other and at the same ice depth, such as three of the four largest observed ones (Fig. 1c), could also produce a deposit essentially parallel to the margin. The compressive ice flow in the ablation area is a process which also acts in favour of orientations parallel to the front. Due to compressive flow, a supraglacial sediment accumulation that has been transported by the ice over the glacier tongue will, to some extent, be compressed in the ice flow direction. Furthermore, ice-cored hills with the same type of sediment cover but with a nearly circular shape are, according to our observations, present higher up on the glacier. A circular accumulation is more difficult to explain by up-thrusting from the bed than a ridge-shaped accumulation.

Another observation that argues against the idea of thrusting is that the sediment accumulations were originally located high up on the glacier front, where the ice depth is fairly large. The sediments have been transported by ice movement since at least 1960 (Krüger, 1994). Accumulations found in 1994 about 1 km from the terminus must have been situated at least 1.5 km further up-glacier in 1960, judging from the observed movement of the largest ridge. Sediment accumulations therefore must have been present at least 2.5 km from the terminus in 1960 (Fig. 1c). According to radio-echo soundings (unpublished information from H. Björnsson, F. Pálsson and M. T. Gudmundsson, 1993), the bed topography is smooth and horizontal for several kilometers under the glacier, giving an increasing ice thickness in the up-glacier direction. Therefore, the higher sediments are located on the glacier, the more difficult it becomes to explain their presence on the surface by up-thrusting from the bed. At 2.5 km from the terminus, the ice thickness is at least about 150 m. Here, it is unlikely that material would be up-thrusted from the bed, especially considering that the ice is entirely temperate (personal communication from H. Björnsson) and that the bed is flat. Finally, the absence of striae on the sediment clast material (Krüger, 1994, p. 118, and authors' observations) indicates that the last transportation process before the supra- and/or englacial deposition was fluvial, not basal transport followed by shearing.

We think that the fossil large-scale englacial drainage system provides the most plausible explanation for the transportation of the sediments found on the ice-cored hills and ridges on Kötlujökull. Our observations indicate that sediments may be transported in water-filled conduits at high elevations within the glacier, much in the same way as discussed by Kirkbride and Spedding (in press) from studies in New Zealand and Iceland. A problem with this explanation is to find the process by which sediment is entrained into the englacial system. We do not have a satisfactory explanation for this, but still think that the association between the conduits and the esker-like material, and the observations of sediment inside the conduits, are strong evidence for fluvial transportation.

Normal meltwater production from summer surface melt cannot account for the large amounts of water needed for the formation of conduits the size of those seen in Figure 3. A much larger meltwater producing event must have occurred. The active volcano Katla is located beneath the central parts of Mýrdalsjökull (Fig. 1b), a combination famous for producing catastrophic floods, or jökulhlaups, during volcanic eruptions. We suggest that the observed englacial drainage system formed at a time of increased geothermal activity. This could have resulted in a jökulhlaup-like event, with much more meltwater present than usual. Such an event could explain the large size of the conduits and the transportation of large amounts of coarse sediments.

ACKNOWLEDGEMENTS

The field observations were made during the Nordic Course in Dynamic Glacial Geomorphology and Sedimentology held in Iceland in August 1994. The course was funded by NorFA (Nordisk Forskerutdanningsakademi) and elegantly arranged by Dr J. Krüger, Institute of Geography, University of Copenhagen. Professor H. Björnsson, Science Institute, University of Iceland, provided valuable information for the discussion. Dr J. Boyle kindly corrected the English.

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7 December 1995

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