Fast ice flow of a surging glacier on a decoupled substrate, and its significance for end moraine formation

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In 1890 and 1964, Brúarjökull, a surge-type glacier in Iceland, advanced 10 and 8 km, respectively, during a few months before returning into quiescence. During these surge events, a streamlined 'low-velocity' landscape, indicating coupling between the ice and its bed, was formed, while the ice-flow velocities were at least 5m/hr. The objective of our study was to resolve the enigma of how such extreme ice velocities were sustained, while the streamlined landscape was being shaped underneath the ice. The study also aimed at the relation between the flow mechanisms and the formation of landforms, such as end moraines, in the glacier forefield. We have erected a new model for the driving mechanism during surge that in turn provides a basis for reconstructing the sequence of developments during end-moraine formation. This study has wider implications for ice sheet stability and the mode of operation for fast-flowing ice, as well as for the understanding of the relation between the flow mechanisms and the formation of glacial landforms.

Earlier ideas of the flow mechanisms of surging glaciers presume that the principal movement occurs across the ice/bed interface, due to dispersed pressurized water and consequent decoupling. This would minimize subglacial sediment deformation during the surge phase. However, subglacial generated landforms in the forefield of Brúarjökull show distinct evidence of deformation during the whole surge phase, e.g. flutes, indicating a strong coupling between the glacier and its substrate. New sedimentological investigations at Brúarjökull reveal a widespread system of water-escape structures (WES) paralleling the surface of the impermeable bedrock beneath. These WESs indicate the presence of pressurized water at the substrate/bedrock interface. This implies that the subglacial sediment succession, coupled to the ice through sediment deformation, was decoupled from the bedrock, at which the principal movement took place. In certain areas, the drainage of the pressurized water from the substrate/bedrock interface has caused the substrate to become coupled to the bedrock underneath. Such areas, or 'sticky spots', likely acted as zones of compression within the dislocated sediment succession and led to the formation of compressive landforms, such as end moraines along the ice margin. The most prominent end moraines, defined as *push moraines*, are found in low lying areas and primarily result from ductile deformation of 3-4 m thick soft-sediment succession. However, brittle deformation becomes frequent at the later stages of the compression phase. It is proposed that these push moraines formed without considerable permafrost in the sediments. However, patches of permafrost in front of the moraines are thought to have resisted the forward advance of the push moraines in some places, and increased the local compression. It is furthermore suggested that seasonal frost played an important role in the rheology of the uppermost strata by increasing their shear strength, causing domination of ductile deformation.

This study may increase the understanding of flow mechanisms and the ice-bed interaction of surging glaciers and ice streams, and might be applied outside Iceland where ice and its immediate substrate overlie an aquitard. Moreover, this study increases the understanding of the morphology, structural geology and formation of end moraines associated with fast flowing ice, and their relation to conditions at the ice/bed and substrate/bedrock interfaces.