Geophysical Research Abstracts
Vol. 19, EGU2017-3481, 2017
EGU General Assembly 2017

An ice stream life cycle: new insights from analog modeling

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In order to understand the relationships between subglacial water drainage and ice flow, we have conducted innovative experiments to study ice stream dynamics through a complete cycle from birth to death. In these analog experiments, the substratum and the ice are respectively simulated by sand and silicon putty, while subglacial meltwater production is simulated using a punctual injection of water in the substratum. We placed markers at three levels (base, mid-thickness and surface) of the silicon putty to follow simultaneously the evolution of the subglacial drainage system, the ice flow dynamics and the formation of tunnel valleys. Here, we address the relationships between (1) meltwater subglacial drainage types (distributed vs. channelized), (2) temporal evolution of subglacial meltwater drainage efficiency, (3) tunnel valley formation and (4) ice stream life cycles.

The experiments show that a corridor of fast flowing-ice (flowing 20 times faster than the surrounding ice) is induced by the generation and migration of subglacial water pockets at the ice-bed interface, illustrating an ice stream birth. The water pockets migrate until they suddenly drain when they reach the ice front, leading to an acceleration of ice flow and a drop in basal water pressures. The absence of visible channels at the ice/substratum interface during migration and drainage of the water pockets reveals a distributed type of drainage during this ice stream generation phase. Then, sudden emptying of the water pockets induces substratum erosion and formation of subglacial topographic depressions at the ice margin. Once the pockets are emptied, subglacial meltwater drains through an efficient channelized drainage system settled in these topographic depressions. Channelization of water flow leads to substratum erosion and tunnel valley formation within a wider decoupled corridor that sustains ice streaming parallel to tunnel valley axes. Tunnel valley abandonment and migration associated with oscillating pressure and migration of ice stream corridors indicate subglacial water piracy mechanisms related to changes in drainage efficiency within the existing tunnel valley systems. Once the number and size of tunnel valleys are sufficient to drain efficiently the meltwater, subglacial overpressures decrease, the decoupled area reduces in extent causing the ice stream to shut down. Tunnel valleys thus appear to be a major component of the subglacial hydrological system securing ice sheet stability as they drain the excess of meltwater responsible for ice flow speeding up.