Surging glacier landsystem

Glaciers gain mass in their upper reaches (accumulation zone) and lose mass at their snout (ablation zone). The majority of glaciers flow (and transfer mass) at a steady rate. However, some glaciers switch between periods of slow and fast flow.

Surging glaciers have relatively long periods of ice build-up and slow ice flow before a sudden release of mass and a short-lived period of much faster (sometimes up to 1000 times faster) ice flow[1,2]. These surge cycles are largely driven by internal processes and are *unrelated to climate*[3,4] (note, however, that surge glaciers are generally found within an optimal climate envelope[5]).

The surge of Variegated Glacier, Alaska, in 1982–83 recorded by timelapse photography. (*my advice: turn sound off*!)

The two phases of glacier surging are known as the *active* phase and *quiescent* phase[6]. In the active phase, ice is moved rapidly from a reservoir zone (most commonly high up on the glacier) to the snout. In this phase, ice may flow at a rate of 10s of metres per day. This fast transfer of mass also tends to cause an advance of the glacier snout. In the quiescent phase between surges, glacier flow slows down, the snout stagnates, and ice once again builds up in the reservoir zone. The active phase of a surge can last from 1 year to 3-10 years, whereas the quiescent phase can be 10s or even 100s years long[7,8,9].

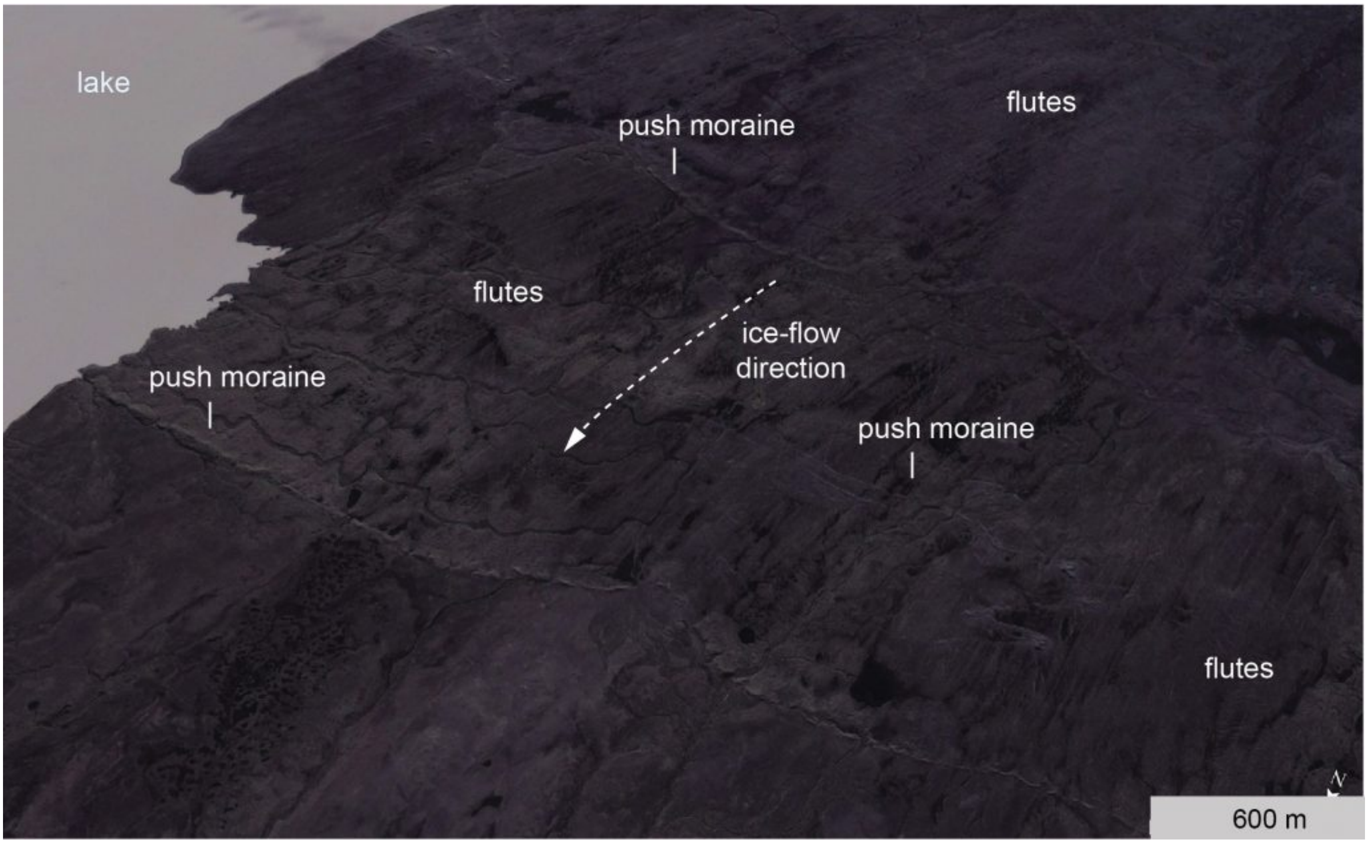
As glacier fluctuations are commonly used to reconstruct past climate changes, the ability to distinguish between climate-driven advances and those not related to climate (i.e. glacier surges) is important.

There is no one landform on its own that is indicative of glacier surging. However, glacier surges leave behind a distinctive assemblage (or group) of landforms in the landscape.

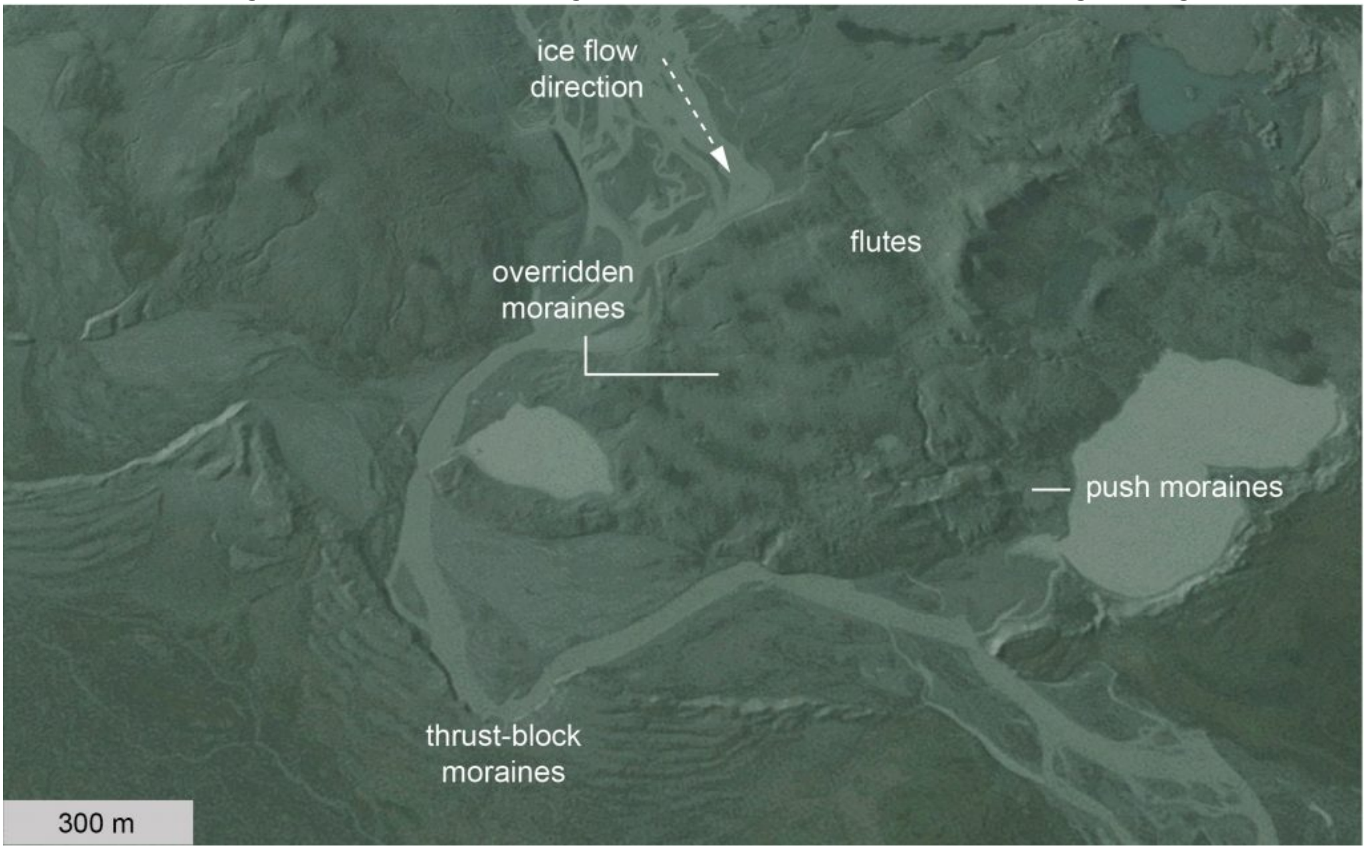
Landform assemblages of surging glaciers

Push moraines and thrust-block moraines

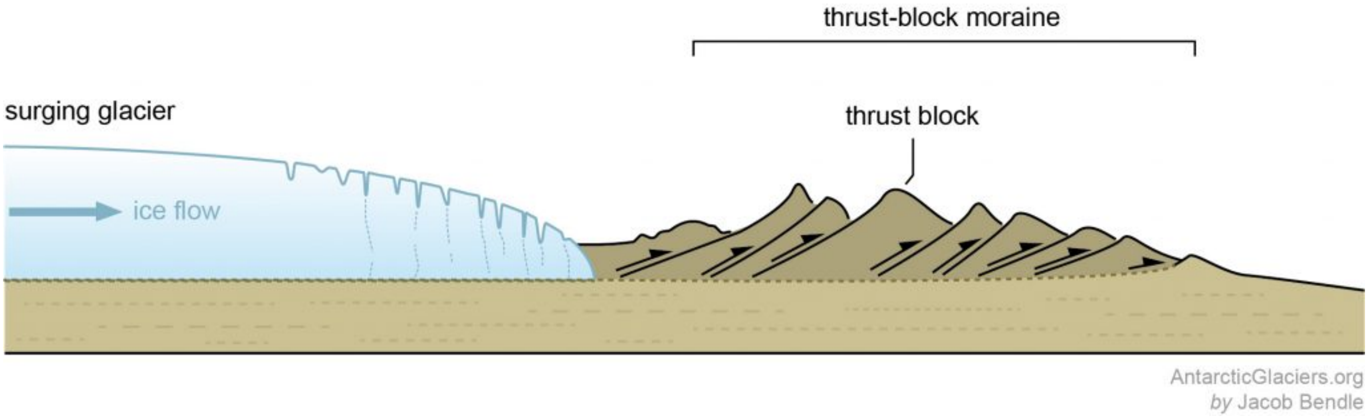
The maximum limit of a surge is marked by moraines[10,11]. These may be single ridge push moraines, or zones of multiple closely spaced ridges that are pushed up in a single 'block' as a rapidly advancing snout deforms, compresses, and 'thrusts up' sediment on the glacier foreland. For this reason, these are known as thrust block moraines.



Push moraine ridges on the foreland of the Brúarjökull surge-type glacier in southern Iceland. Notice how sets of flutes grade to the moraine ridge. (see ref. 11 for further detail). Image: Google Earth.



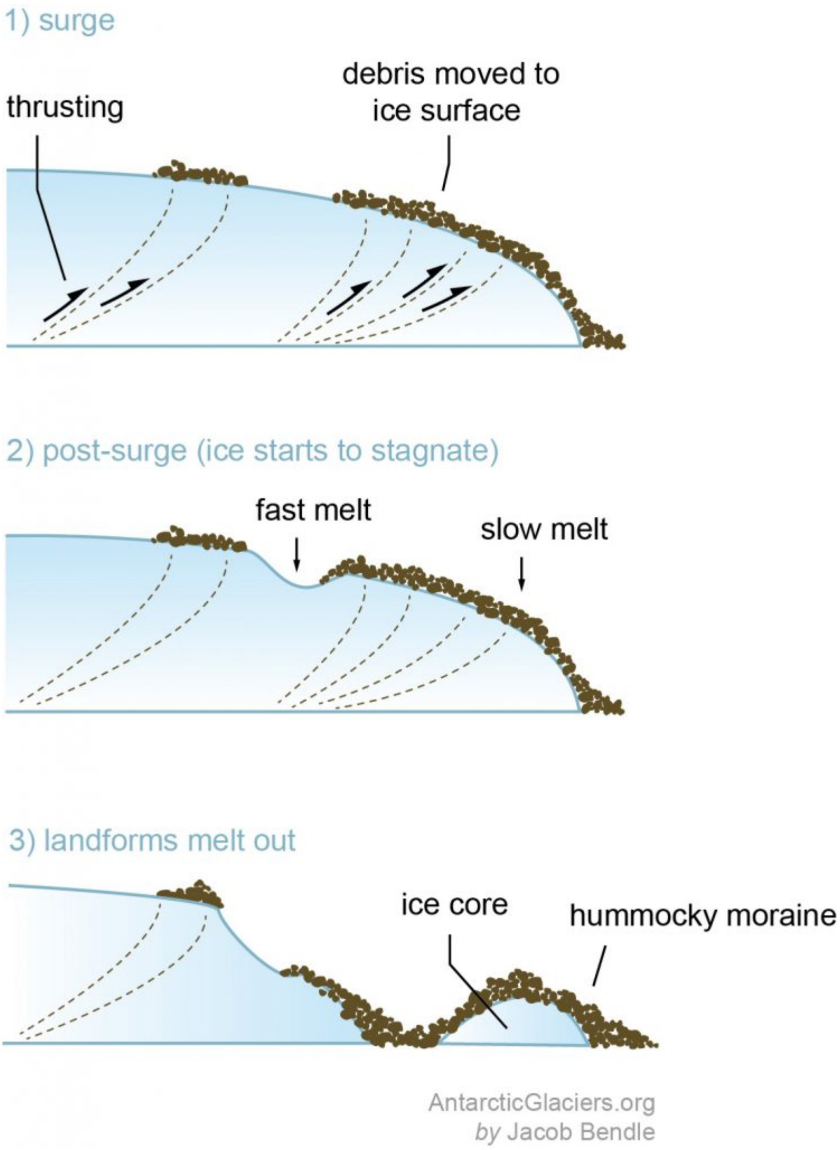
Thrust-block moraines on the foreland of the Eyabakkajökull surge-type glacier in southern Iceland. Notice how each thrust block contains multiple ridges. (see ref. 11 for further detail and diagram below for explanation). Image: Google Earth.



Thrust-block moraines form as proglacial sediments are deformed ('thrust up') by the rapidly advancing surge snout. This creates a thrust moraine zone with numerous distinct ridges.

Hummocky moraine

During a surge, rapid flow causes the ice to stretch, bend, fold and fracture[7]. This deformation of ice (particularly a process known as 'thrusting') can move large volumes of sediment from the bed (or from within the glacier) up on to the glacier surface[12]. In the quiescent phase, after the surge has taken place, the melting of the stagnant snout gradually lowers this sediment to the land surface, where it forms a zone of hummocky mounds and hollows.

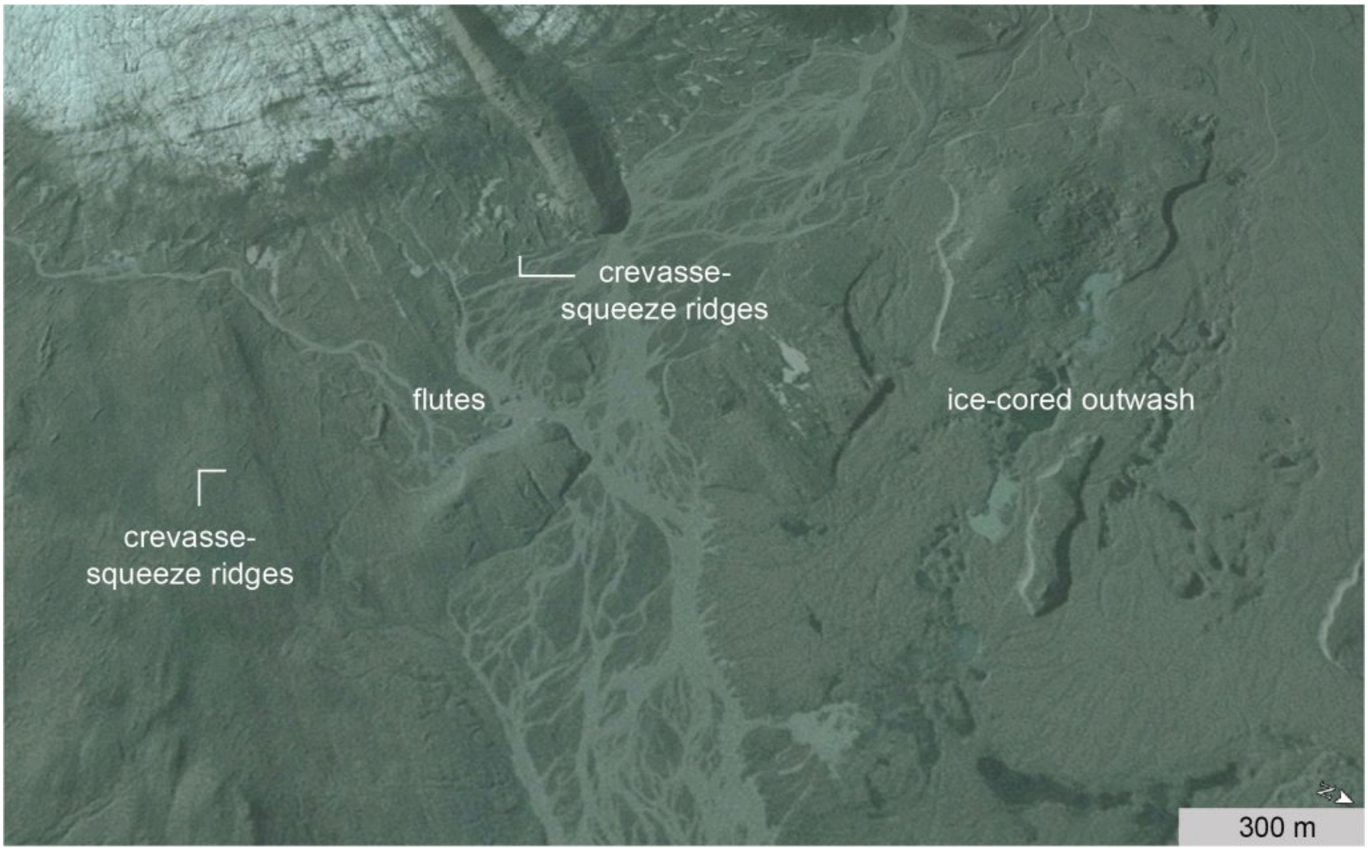


A simplified model of hummocky moraine formation owing to the thrusting of debris to the ice surface during a surge. Sediment is thrust to the glacier surface in the active phase. In the quiescent phase, the snout stagnates and melting gradually lowers debris to the land surface. Over time, moraine ice cores melt away leaving behind hummocky topography.

In the surging glacier landsystem[10,11], belts of hummocky moraine can be found on the ice-contact slopes of push moraines or thrust-block moraines, as this is the area where stagnating ice develops most extensively during the quiescent phase.

Ice-cored outwash

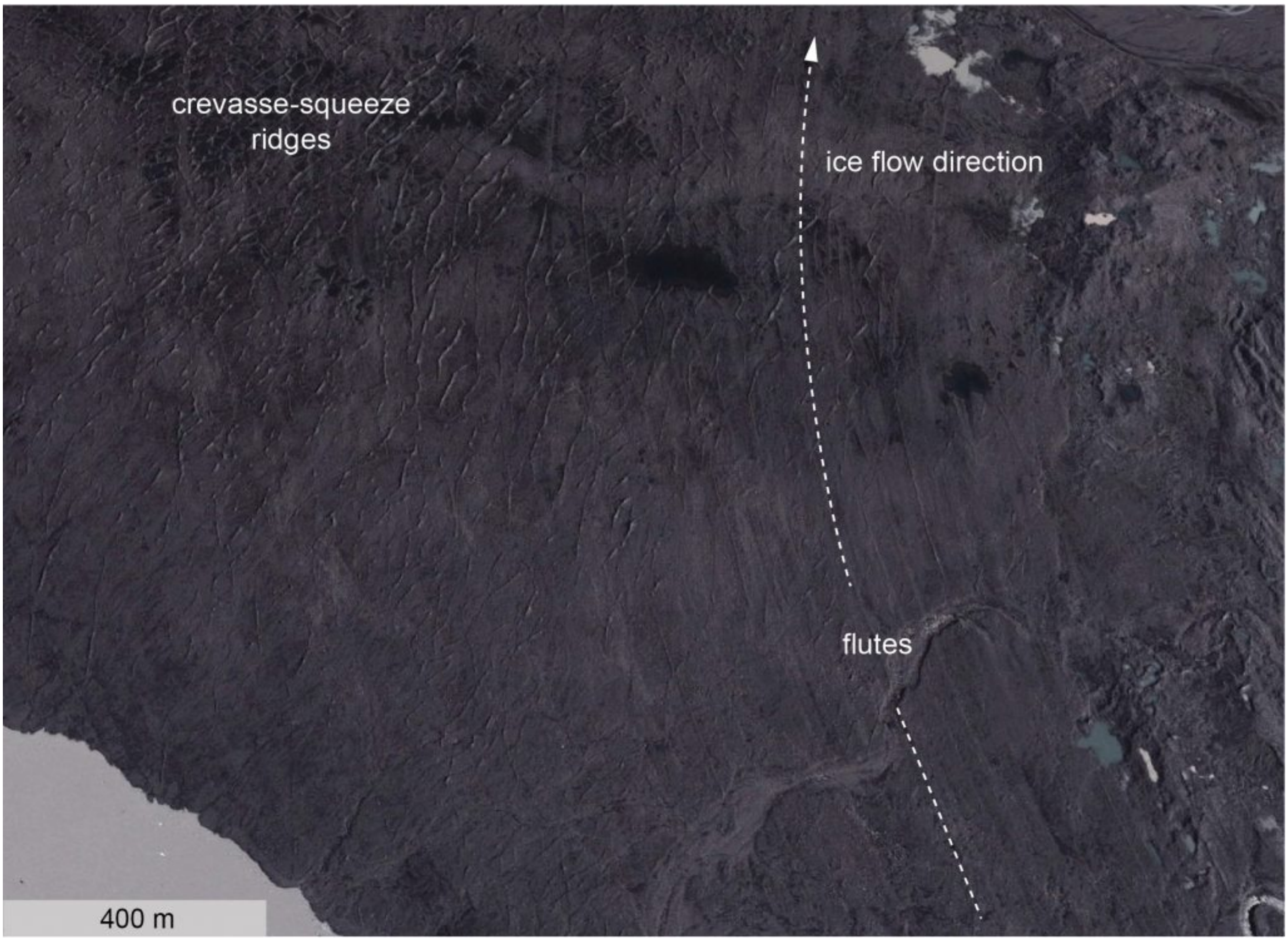
Another common feature of surge glacier forelands are areas of ice-cored outwash[10,11]. Toward the end of surge, some glaciers release large volumes of meltwater that transport and deposit sediment across the stagnant glacier snout. As this sediment-covered ice melts over time, small lakes (kettles) may form at the outwash surface.



Ice-cored outwash on the foreland of the Eyabakkajökull glacier in southern Iceland. The numerous small lakes that give the outwash a ‘pitted’ appearance form as buried ice melts out over time (see ref. 11 for further details). Image: Google Earth.

Flutes

Flutes are streamlined ridges of sediment formed at the glacier bed. In themselves, flutes are not diagnostic of glacier surging, as they are found at many temperate glacier types. However, flutes formed by a glacier surge are often particularly long (over 1 km long in some cases) and unbroken, as they were created by a single, rapid glacier advance[13].



Long (100s of metres) flutes and crevasse-squeeze ridges preserved on the foreland of the Brúarjökull surge-type glacier in southern Iceland. Notice how the crevasse-squeeze ridges do not parallel ice flow, but cut obliquely across streamlined flutes (see ref. 11 for further detail). Image: Google Earth.

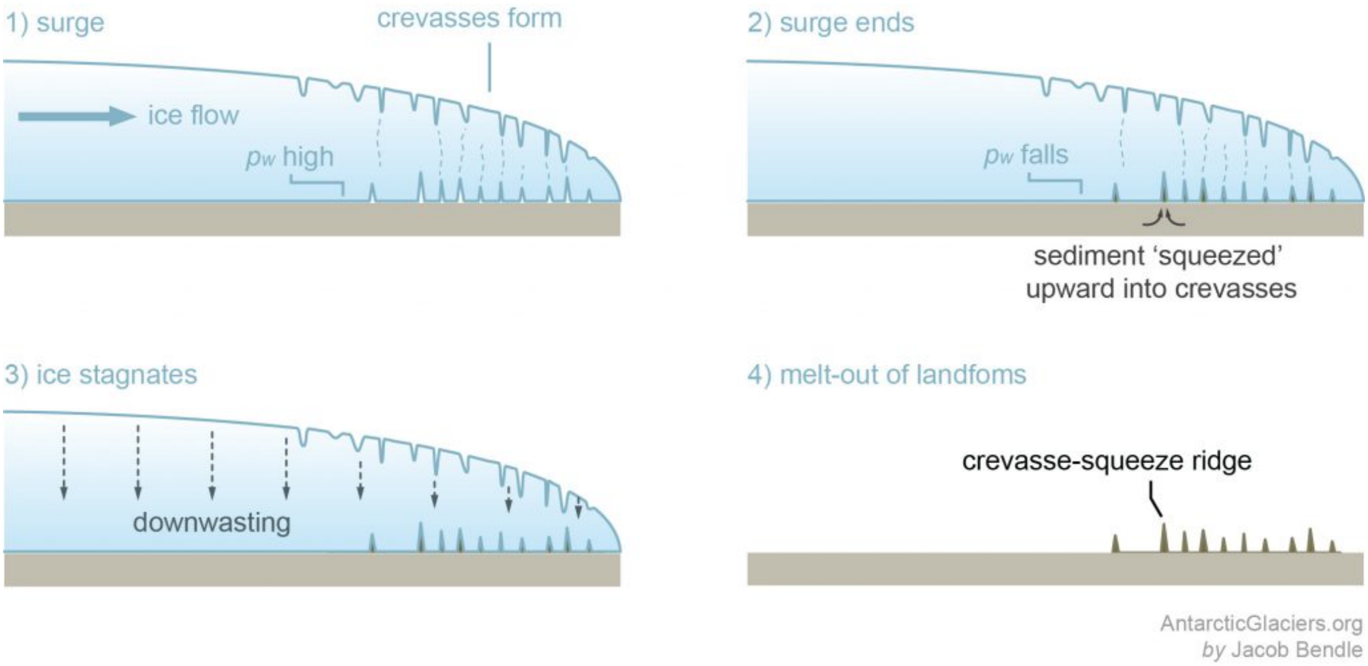
In contrast to non-surging glacier types, flutes are often also found is close association with crevasse-squeeze ridges (see below) when formed during surges.

Crevasse-squeeze ridges

During a surge, glacier ice stretches and fractures[7], which creates many crevasses that pass all the way through the glacier (*video below*), from the ice surface to the bed.

A helicopter flight over a surging glacier in Yukon's Saint Elias Mountains shows extensive crevassing during the active phase of a surge. (note: Gwenn Flowers of Simon Fraser University also provides a great explanation of glacier surging and why surge-type glaciers are important). Filming: CBC News: The National.

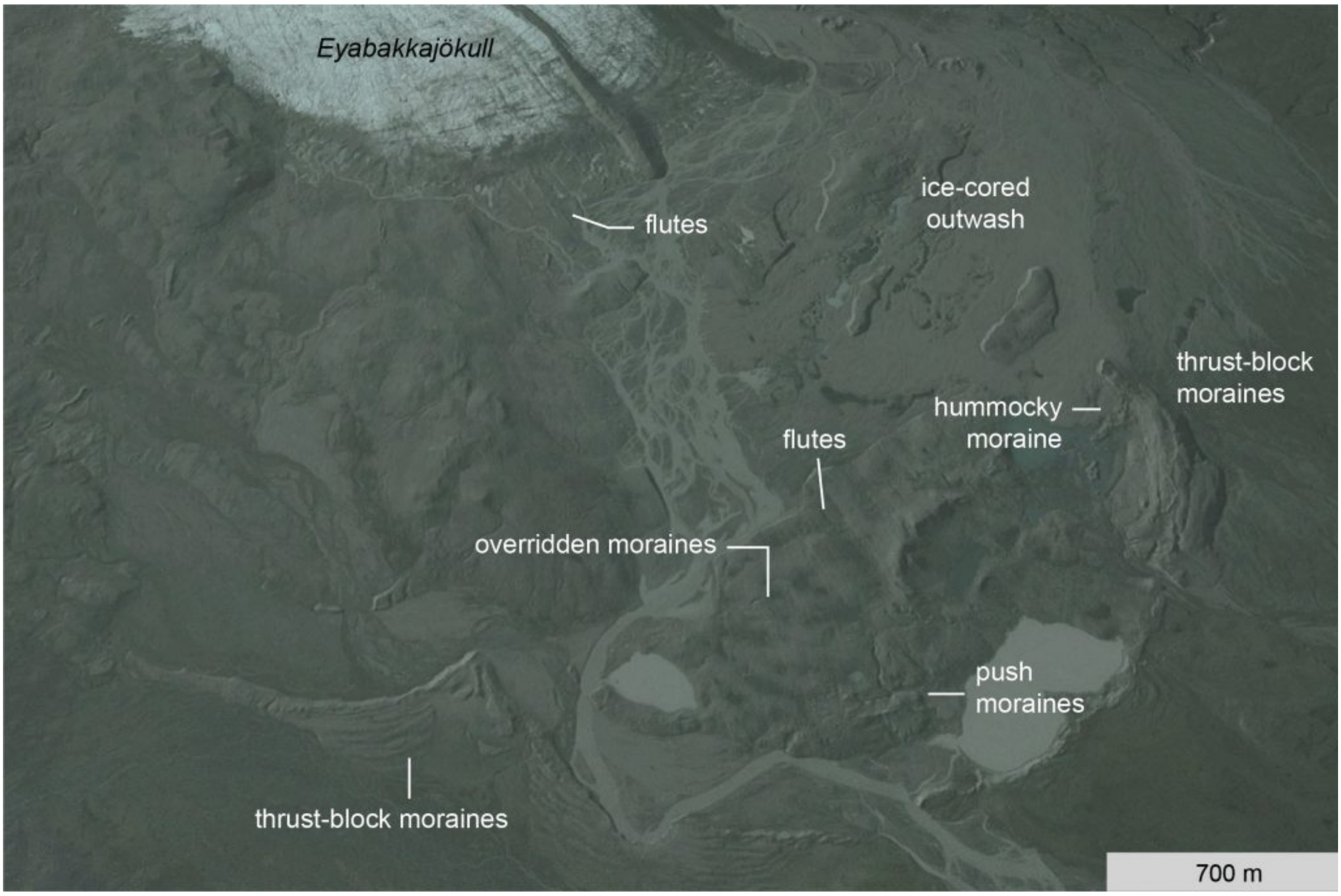
Once the surge is over (when there is a drop in basal water pressure) sediment is squeezed upwards into open basal crevasses. As the snout stagnates and ice melts away during the quiescent phase following a surge, a cross-cutting network of crevasse-squeeze ridges is left behind in the landscape[12,14].



A simplified explanation of crevasse-squeeze ridge formation by glacier surging. 1) Crevasses form through the snout during the active surge phase. 2) A drop in basal water pressure (*pw*) following the surge allows sediment to fill basal crevasses. 3) The glacier snout stagnates and thins in the quiescent phase. 4) Melting of glacial ice leaves behind crevasse-squeeze ridges in the landscape.

The surging glacier landsystem

While there are slight differences from glacier to glacier, the surging glacier landsystem[10,11] tends to be spatially arranged in three main zones: an *outer zone* of push and thrust-block moraines (this represents the maximum extent of a surge), an *intermediate zone* of hummocky moraine (where snout stagnation occurs post-surge), and an *inner zone* of flutes, crevasse-squeeze ridges (where ice has overridden the foreland), and areas of ice-cored and pitted outwash.



The surging glacier landsystem of Eyabakkajökull glacier in southern Iceland (see ref. 11 for further details). Note the *outer zone* of push and thrust-block moraines, the *intermediate zone* of hummocky moraine, and the *inner zone* of flutes, crevasses-squeeze ridges and overridden moraines. Image: Google Earth.

Because glacier surging is cyclical in nature, the surging glacier landsystem may also contain evidence of several surge events, such as overridden moraines, which are smoothed by the overriding ice and often have flutes across their surface.

In summary, surging glaciers leave a distinct imprint on the land surface. No one landform is concrete evidence of a past glacier surge, but where a full assemblage of landforms (the surging glacier landsystem) occurs, the activity of past surging glaciers (in areas that are no longer glaciated) can be studied and reconstructed[15,16].

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