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Sub-annual moraine formation at an active temperate Icelandic glacier

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We present findings from detailed geomorphological and sedimentological investigations of small recessional moraines at Fjallsjökull, an active temperate outlet of Öræfajökull, southeast Iceland. The moraines are characterised by striking sawtooth or hairpin planforms that are locally superimposed, giving rise to a complex spatial pattern. We recognise two distinct populations of moraines, namely a group of relatively prominent moraine ridges (mean height ~1.2 m) and a group of comparatively low-relief moraines (mean height ~0.4 m). These two groups often occur in sets/systems, comprising one pronounced outer ridge and several inset smaller moraines. Using a representative subsample of the moraines, we establish that they form by either (a) submarginal deformation and squeezing of subglacial till or (b) pushing of extruded tills. Locally, proglacial (glaciofluvial) sediments are also incorporated within the moraines during pushing. For the first time, to our knowledge, we demonstrate categorically that these moraines formed sub-annually using repeat uncrewed aerial vehicle (UAV) imagery. We present a conceptual model for sub-annual moraine formation at Fjallsjökull that proposes the sawtooth moraine sequence comprises (a) sets of small squeeze moraines formed during melt-driven squeeze events and (b) push moraines formed during winter re-advances. We suggest the development of this process-form regime is linked to a combination of elevated temperatures, high surface meltwater fluxes to the bed, and emerging basal topography (a depositional overdeepening). These factors result in highly saturated subglacial sediments and high porewater pressures, which induces submarginal deformation and ice-marginal squeezing during the melt season. Strong glacier recession during the summer, driven by elevated temperatures, allows several squeeze moraines to be emplaced. This process-form regime may be characteristic of active temperate glaciers receding into overdeepenings during phases of elevated temperatures, especially where their englacial drainage systems allow efficient transfer of surface meltwater to the glacier bed near the snout margin.