

# **The role of glaciohydraulic supercooling in the formation of debris-rich basal ice: insights from particle size analysis**

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## I Background

The basal ice layer of temperate glaciers (those at the pressure melting point throughout) is typically only expected to reach up to one metre in thickness and is sometimes absent. There are several reports, however, of up to 15m thick basal ice layers at temperate glaciers. Glaciohydraulic supercooling might explain this anomaly. Supercooling may operate beneath glaciers situated within overdeepened basins where subglacial water ascends the adverse slope of the overdeepening toward the glacier margin at a faster rate than it can be heated by friction. This water reaches the margin in a supercooled state where it can freeze to the glacier base as anchor and frazil ice which anneal and evolve further to form basal ice. Thick basal ice formed by supercooling could impact significantly upon glacial sediment entrainment and deposition, glacial geomorphology, and glacier dynamics.

There is an alleged sedimentological similarity between anchor and frazil ice grown from supercooled water at discharge vents at the glacier margin and the basal ice that is taken as diagnostic evidence for the accretion of supercooled water to the glacier base. There is also the suggestion that where it occurs, supercooling will be dominant in basal ice formation and that other formative mechanisms play only a minor role in comparison. Furthermore, it has been suggested that basal ice formed by supercooling will necessarily be silt-dominated due to the nature in which it forms (porous frazil/anchor ice accretes to the glacier base and preferentially filters out silt from subglacial water). However, the process-form link between supercooling and basal ice remains controversial because there is a paucity of sedimentological evidence for this hypothesis, and because case studies are now emerging where glaciers that meet the physical conditions for the operation of supercooling lack any evidence for basal ice accretion through supercooled freeze-on. Clearly there is a need for further testing of this process-form link.

This study has two objectives:

1. To test the process-form link between supercooling and basal ice by comparing the particle size distributions of individual basal ice facies with those of anchor and frazil ice.
2. To test the assertion that basal ice formed by supercooling will tend to be silt-dominated by freezing debris-laden supercooled water under experimental conditions and comparing the particle size distributions of the initial water and resultant ice facies.

## II Results for Objective 1

Fieldwork was undertaken at the Svínafellsjökull glacier in southern Iceland. Sediment samples were taken from the five individual facies (A to E) that comprise the debris-rich basal ice, and from anchor and frazil ice, and were processed through

wet sieving and laser granulometry. No frazil ice was observed, however, at Svínafellsjökull so comparisons are here restricted to anchor ice. Kolmogorov-Smirnov analysis was undertaken to test the similarity between the mean basal ice facies particle size distributions and that of the anchor ice. This analysis assumes anchor ice as the reference sediment and tests the significance of the greatest difference between the cumulative size distributions of anchor ice and the basal ice facies. Results are shown in Table 1.

**Table 1** – Summary of the Kolmogorov-Smirnov analysis to test the difference between basal ice facies and anchor ice particle size distributions at Svínafellsjökull.

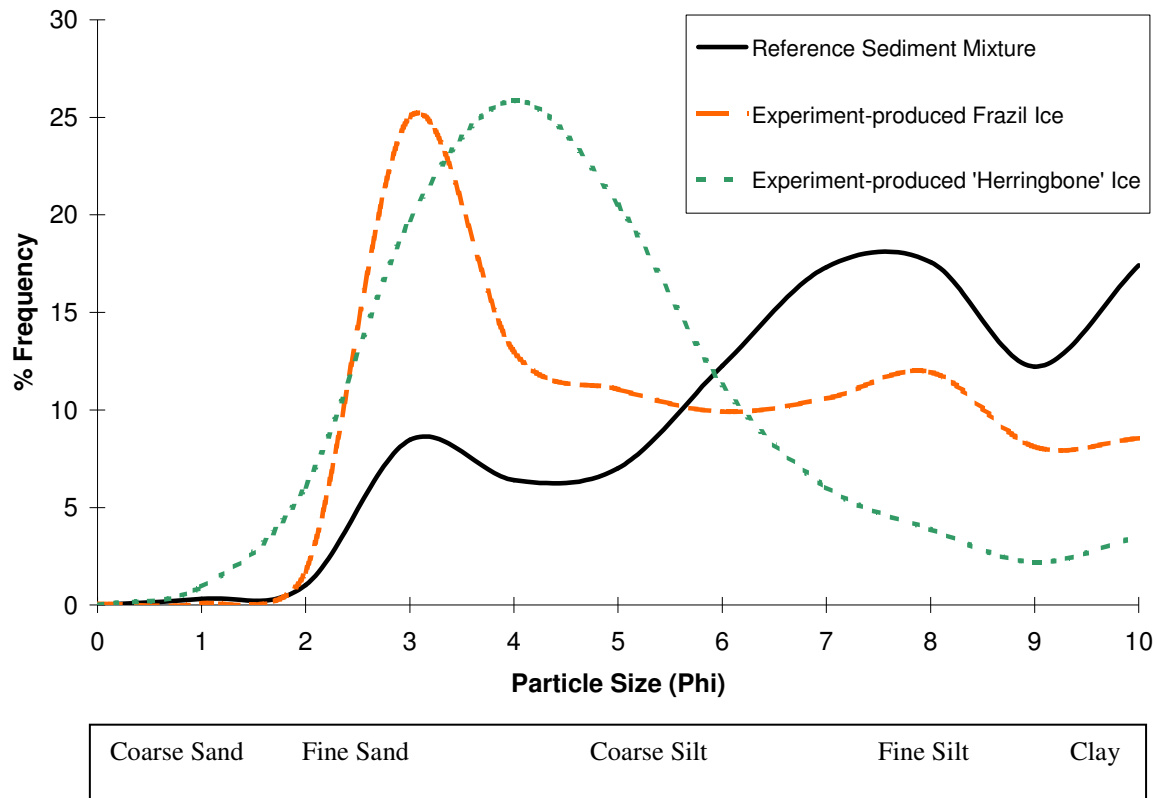
Facies	Sample Size (n)	Greatest Difference (Dstat)	Critical Statistic at 95% sig. (Dcrit)	Critical Statistic at 99% sig. (Dcrit)	Significantly Different?	
					95%	99%
A	16	0.429	0.328	0.392	Yes	Yes
B	10	0.439	0.410	0.490	Yes	No
C	14	0.104	0.349	0.418	No	No
D	5	0.354	0.565	0.669	No	No
E	14	0.390	0.349	0.418	Yes	No

At the 95% significance level three of the five basal ice facies are statistically different from the anchor ice (sub-facies A, B and E), although at 99% significance only sub-facies A is statistically different from anchor ice. Sub-facies C and D are not statistically different from anchor ice. These results show that at least one, and potentially three, of the basal ice facies are sedimentologically different to anchor ice and are therefore difficult to reconcile with an origin by glaciohydraulic supercooling. The supercooling hypothesis is retained for the remaining two basal ice facies.

### III Results for Objective 2

A tub of debris-laden water was placed in a cold room at  $-3^{\circ}\text{C}$  with a turbulence source and allowed to cool. Turbulence depresses the freezing point and allows the water to supercool. After five days the turbulence was switched off and the supercooled water allowed to freeze. Two ice facies were formed. The first was a frazil ice type that formed over the surface of the tub during cooling of the turbulent water, and the second a ‘herringbone’-textured ice facies that formed in the centre of the tub after the turbulence was switched off. Sediment samples were taken from each facies along with samples of the initial sediment and processed using laser granulometry to derive particle size distributions. Figure 1 presents the results of this experiment.

There is a clear change in the particle size distribution of the two ice facies investigated compared to the parent sediment (Figure 1). Both the experimentally-produced frazil ice and ‘herringbone’ facies seem to preferentially entrain fine sand to coarse silt relative to the parent sediment, and preferentially reject sediment sizes finer than  $6\Phi$  (coarse to medium silt) relative to the parent sediment. These results suggest that under experimental conditions, ice facies associated with freezing turbulent supercooled water do not necessarily preferentially entrain silt-sized material.



**Figure 1** – Particle size distributions for the experimentally produced ice facies and the initial sediment in the water. Five samples have been averaged to produce a mean distribution for each sediment type.

#### IV Conclusions

There are two key findings from this work relating to the two objectives listed in Section I:

1. Not all of the basal ice is sedimentologically similar to anchor ice at Svínafellsjökull suggesting that not all basal ice can be attributed to formation by glaciohydraulic supercooling. This calls into question previous suggestions that glaciohydraulic supercooling should be dominant in basal ice formation where it occurs.
2. Ice facies produced under experimental conditions by freezing turbulent supercooled water do not show preferential entrainment of only silt-sized sediment textures. This calls into question the assumption that silt-dominated sediment textures are unique to the supercooling process and can be used to identify the operation of supercooling in contemporary or former glacial environments.

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