

Landscapes that experience glaciation undergo considerable modification as a result of the erosion caused by the moving masses of ice. (Photo) Direct glacial erosion is accomplished by three processes: abrasion, crushing and plucking. Another important, but indirect erosion process is meltwater erosion.



A large-scale U-shaped valley carved out by the action of glacial erosion

**Abrasion:** Abrasion involves the wearing down of rock surfaces by the grinding effect of rock fragments frozen into the base of glaciers. A good analogy of this process is sand papering and through its action it produces smoothed bedrock surfaces that often exhibit parallel sets of scratches (1-10mm diameter), called striations. Abrasion forms fine silt-sized particles (0.1mm) known as rock flour, which causes the milky appearance of meltwater streams.



Striations on a glacially scoured rock surface

The effectiveness of abrasion has been confirmed by direct observation of the ice/bedrock interface in tunnels drilled into glaciers. During the 1970s Geoffrey Boulton, a leading glacial geomorphologist, fixed rock plates (composed of marble) in front of moving ice at the base of two glaciers. After the glacier had overridden the plates they were removed and inspected (Table 1).

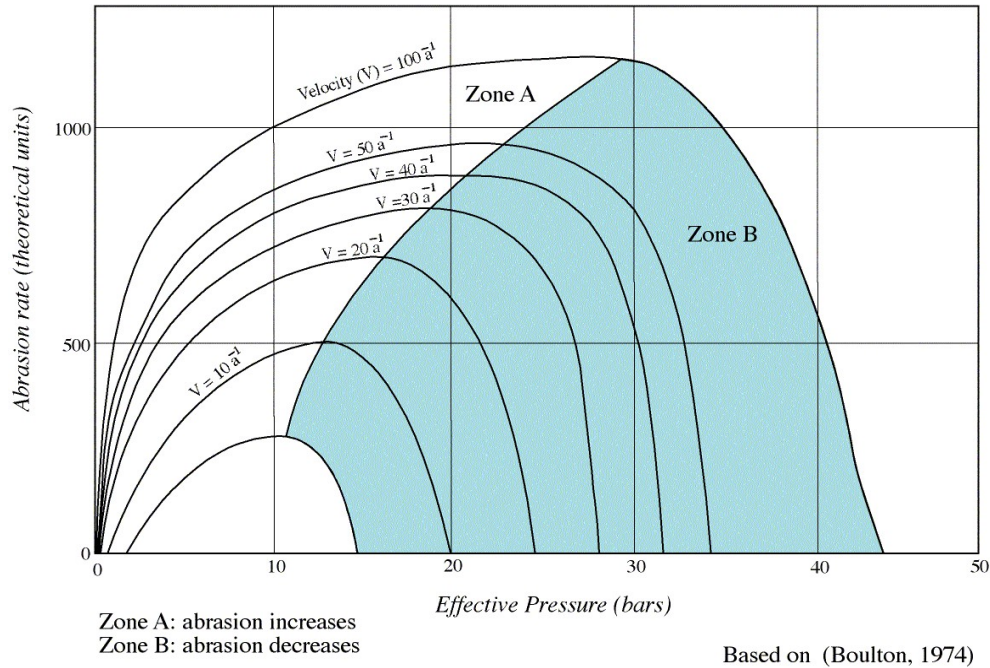


Melt water stream: snout of Glacier de Argentiere

Glacier	Abrasion rate	Ice thickness	Velocity
Breidamerkerjokull 1 (Iceland)	3 mma <sup>-1</sup>	40 m	9.6 ma <sup>-1</sup>
Breidamerkerjokull 2	3.4 mma <sup>-1</sup>	15 m	19.5 ma <sup>-1</sup>
Breidamerkerjokull 3	3.75 mma <sup>-1</sup>	32 m	15.4 ma <sup>-1</sup>
Glacier d Argentiere (France)	36 mma <sup>-1</sup>	100 m	250 ma <sup>-1</sup>

Table 1. Rates of glacial abrasion. Source Boulton 1974.

The field results were then used by Boulton to construct a theoretical model of glacial abrasion (Fig). This model demonstrates that the rate of abrasion initially increases as glacial pressure and ice velocity increase. However, if the pressure becomes too great ice at the base of the glacier begins to melt, releasing the abrading rock fragments from their icy bond, which in turn reduces the rate of abrasion.



Theoretical relationship between abrasion rate, ice velocity and pressure

Other factors that influence abrasion include;

**Ice velocity:** abrasion is greater beneath fast flowing glaciers since more debris passes a given point per unit of time.

**Basal rock debris:** abrasion can only occur if rock debris is present at the ice/rock interface. Clean ice cannot scour its rock bed and the rate of abrasion increases with basal debris concentration, furthermore, the abrading rock fragments must be harder than the bedrock surface beneath.

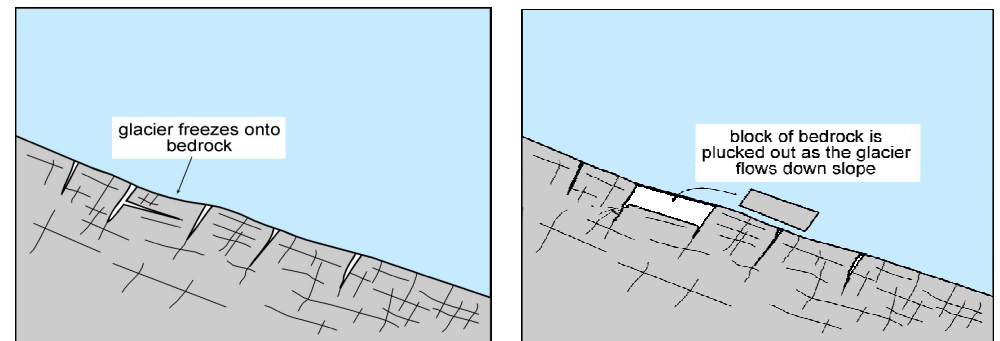
**Removal of rock flour:** in order to sustain abrasion rock flour needs to be flushed away from the glacial sole by a constant supply of melt-water, otherwise the ice/rock interface would clog-up with fine debris

reducing the direct contact between abrading clasts and the underlying rock surface.

The thermal regime of a glacier exerts a strong influence on the nature of erosion. For instance, the rate of abrasion beneath polar glaciers will be negligible owing to the lack of basal sliding. However, the greater adhesion of cold ice to bedrock creates more effective conditions for plucking. The most effective erosion probably occurs beneath polythermal glaciers since both abrasion and plucking operate here.

**Crushing:** Crushing occurs when the pressure exerted by basal rock fragments crushes the bedrock surface beneath to leave crescentic fractures called chattermarks.

**Plucking:** Plucking is the removal of well jointed or loosened blocks of bedrock by an overriding glacier. Blocks freeze onto the glacier sole and are then pulled clear of the rockmass as the ice moves forward. Once plucked the blocks become the grinding tools that cause abrasion. Plucking is particularly effective where a glacier flows over rock that has already been weakened by frost weathering.

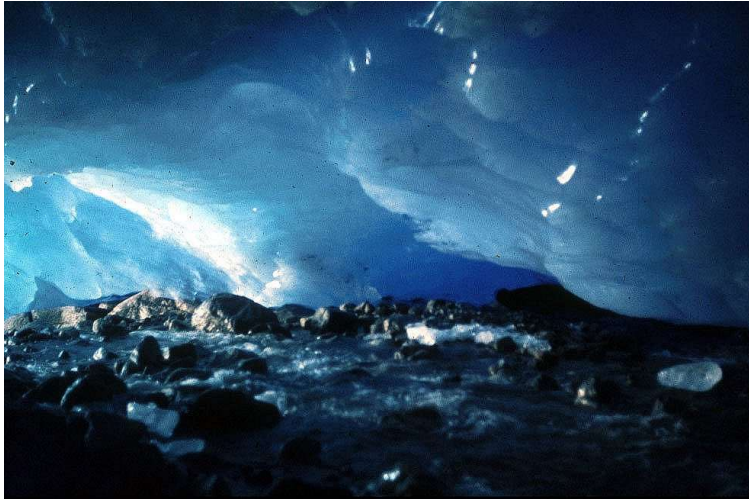


The excavation of bedrock beneath a glacier by plucking



**Meltwater Erosion:** The streams of meltwater that flow along the base of a glacier erode rock in the same way as surface streams, through the combined action of abrasion, hydraulic action, attrition, and solution. However,

there is one important difference, water at the base of a glacier is squeezed by the enormous weight of ice above (hydrostatic pressure). This causes meltwater streams to flow much faster, hence, the erosive potential of meltwater streams is significantly greater than surface rivers.



Subglacial stream system at Nigardsbreen, Norway.

Rock surfaces smoothed and moulded by the action of meltwater erosion

