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## Annual moraines at Gornergletscher, Switzerland – markers of a retreating mountain glacier

In a globally warming climate, mountain glaciers in the European Alps are rapidly shrinking, causing major economic and ecological problems. As we try to better estimate the future fate of Alpine glaciers, knowledge of how they reacted to climatic fluctuations in the past therefore becomes increasingly important. However, detailed documentation in the form of aerial photographs or historical maps is not always available for those time periods and therefore we rely on information stored in glacial sediments and landforms to reconstruct past variations in glacier extent. Annual moraines are a particular type of landform that can help to better constrain those glacial fluctuations and to understand the rates and drivers of glacier retreat.

Essentially, annual moraines are small ridges of sediment that are formed at the margins of seasonally oscillating glaciers. Even if a glacier is in a state of overall retreat, lower temperatures and increased snowfall during the winter months can enable its front to slightly advance. Sediments that are lying in front of the glacier will thereby be pushed up into a ridge that marks the extent of the glacier at the end of the winter season – an annual moraine. If this happens over the course of several years or decades, longer sequences of these moraines can be preserved within the landscape, even at times when the glacier is long gone. This opens the exciting opportunity to trace the retreating glacier back in time and to understand which factors influenced its decline.

In this study, we examined a sequence of annual moraine ridges that has been forming at the margin of Gornergletscher, a large mountain glacier located in the southern Swiss Alps. The goal was to understand the sedimentary processes behind their formation and to use the moraine record to quantify the rates and understand the drivers of recent retreat. We found that Gornergletscher has been subject to accelerated retreat and frontal thinning during the previous decade. Retreat rates, calculated from annual moraine ridges, show a significant correlation to annual temperatures, indicating that climatic fluctuations could be a major driver of glacial retreat even on annual time scales. However, we also found that annual moraines that have been deposited at the glacier margin during recent years are heavily influenced by the pronounced thinning of the snout. Some of these moraines contain cores of glacier ice that quickly melt out when temperatures in summer are high (Fig. 1). As this can lead to substantial modification and partly even a collapse of the moraine bodies, it becomes increasingly hard to reliably reconstruct the position of the glacier from the landscape record. This indicates major challenges that are connected with using annual moraines as markers of glacial retreat at a thinning mountain glacier.



Fig. 1. Annual moraine ridge at Gornergletscher. How long will this landform be preserved in the landscape given the meltout of the ice core?

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