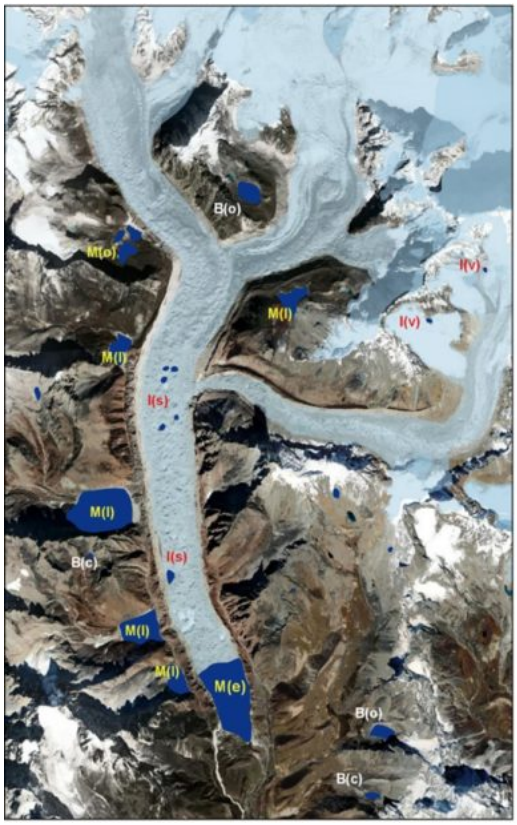
Introduction to Glacial Lakes

What are glacial lakes and where are they found?

During the last few decades, accelerated ice mass loss and glacial retreat has resulted not only the expansion of existing glacial lakes but also the formation of new glacial lakes [1,2]. As a result, glacial lakes are now found across all glaciated regions.



Glacial lake type	Code	Definition
Moraine-dammed lake	**M**	**Lake dammed by moraine following glacial retreat.**
End-moraine-dammed lake	M(e)	Lake dammed by terminal moraines. Usually touches the walls of the side moraines, but the water is held back by the end moraine (dam). Lake is usually, but not necessarily, in contact with the glacier, and may have glacier ice at the lake bottom.
Lateral moraine-dammed lake	M(l)	Lake dammed by lateral moraine(s) (in the tributary valley, trunk valley, or between the lateral moraine and the valley wall, or at the junction of two moraines). Lake is held back by the outside wall of a lateral moraine, i.e., away from the former glacial path.
Other moraine-dammed lake	M(o)	Lake dammed by other moraines (includes kettle lakes and thermokarst lakes).
Ice-dammed lake	**I**	**Lakes dammed by glacier ice, including lakes on the surface of a glacier, lake dammed by glaciers in the tributary/trunk valley, between the glacier margin and valley wall, or at the junction of two glaciers.**
Supraglacial lake	I(s)	Bodies of water (pond or lake) on the surface of a glacier. This is the most common type of ice-dammed lake in the Nepal Himalaya.
Dammed by tributary glacier	I(v)	Lake dammed by glacier ice with no lateral moraines. Can be at the side of a glacier between the glacier margin and valley wall.
Bedrock-dammed lake	**B**	**Bodies of water that form as a result of an earlier glacial erosion process which accumulate in depressions after the glacier has retreated or melted away.**
Cirque lake	B(c)	A small pond occupying a cirque.
Other glacier erosion lake	B(o)	Bodies of water occupying depressions formed by the glacial erosion process. These are usually located on the mid-slope of hills, but not necessarily in a cirque.
Other glacial Lakes	**O**	**Lakes formed in a glaciated valley and fed by glacial, snow, and permafrost melt, but damming material not directly part of the glacial process, e.g. debris flow, alluvial, or landslide blocked lakes.**

Figure 1: Aerial image to illustrate glacial lake types. Codes are as following: M(e)= end-moraine-dammed lake, M(l)= lateral moraine-dammed lake, M(o)= other moraine-dammed lake, I(s)= supraglacial lake, I(v)= valley-glacier ice-dammed lake, B(c)= cirque glacier, B(o)= other bedrock-dammed lake, O= other glacial lake. Adapted from Maharjan et al. (2018). Background image Google Earth 2021.

Why are they important?

While glacial lakes make for a beautiful addition to glacial landscapes, they also present many additional hazards. Firstly, they act as 'hydrological buffers', that interrupt the delivery of water and sediment downstream [3], thus as a result, they can lead to water supply issues in downstream

communities.

Further, they can also amplify ice loss from adjoining glaciers through the process of glacial calving and subaqueous melting [4].

Lastly, and perhaps most importantly, glacial lakes are also the origin of glacial lake outburst floods (GLOFs) and debris flows. It is therefore vital that they are well understood.

Types of glacial lakes

Generally, based on a classification developed by the ICIMOD (The International Centre for Integrated Mountain Development), glacial lakes can be classified into the following categories below. Furthermore, these can be further categorised based on the process of formation, as illustrated in figure 1.

Moraine dammed	Subglacial lakes
Ice dammed	Englacial lakes
Bedrock dammed	Other glacial lakes

Moraine dammed glacial lakes

Figure 2: Image to illustrate a moraine dammed glacial lake at Dig Tsho in the Langmoche valley, Khumbu Himal, Nepal. With permissions from Matt Westoby and annotated by Caroline Taylor.

Firstly we have moraine-dammed glacial lakes, referring to a water body between a moraine ridge and a glacier,. These can then be divided into three subclasses; end-moraine dammed lakes, lateral moraine-dammed lakes, and moraine thaw lakes [6].

Moraine dammed glacial lakes are the second most common type of lake found globally, and also the

most likely to fail and trigger a GLOF [7]. They are generally unvegetated, unconsolidated, and can contain ice cores.

The majority of lateral and terminal moraines that impound present-day glacial lakes were constructed during the Little Ice Age; a globally synchronous period of glacial advance extending from the 15th century to the end of the 19th century [8,9].

Generally, there is two main pathways to the formation of moraine dammed glacial lakes. Firstly, by pooling of meltwater in glacial overdeepenings between the moraine and glacier or secondly, via coalescing of surface ponds.

Ice dammed glacial lakes

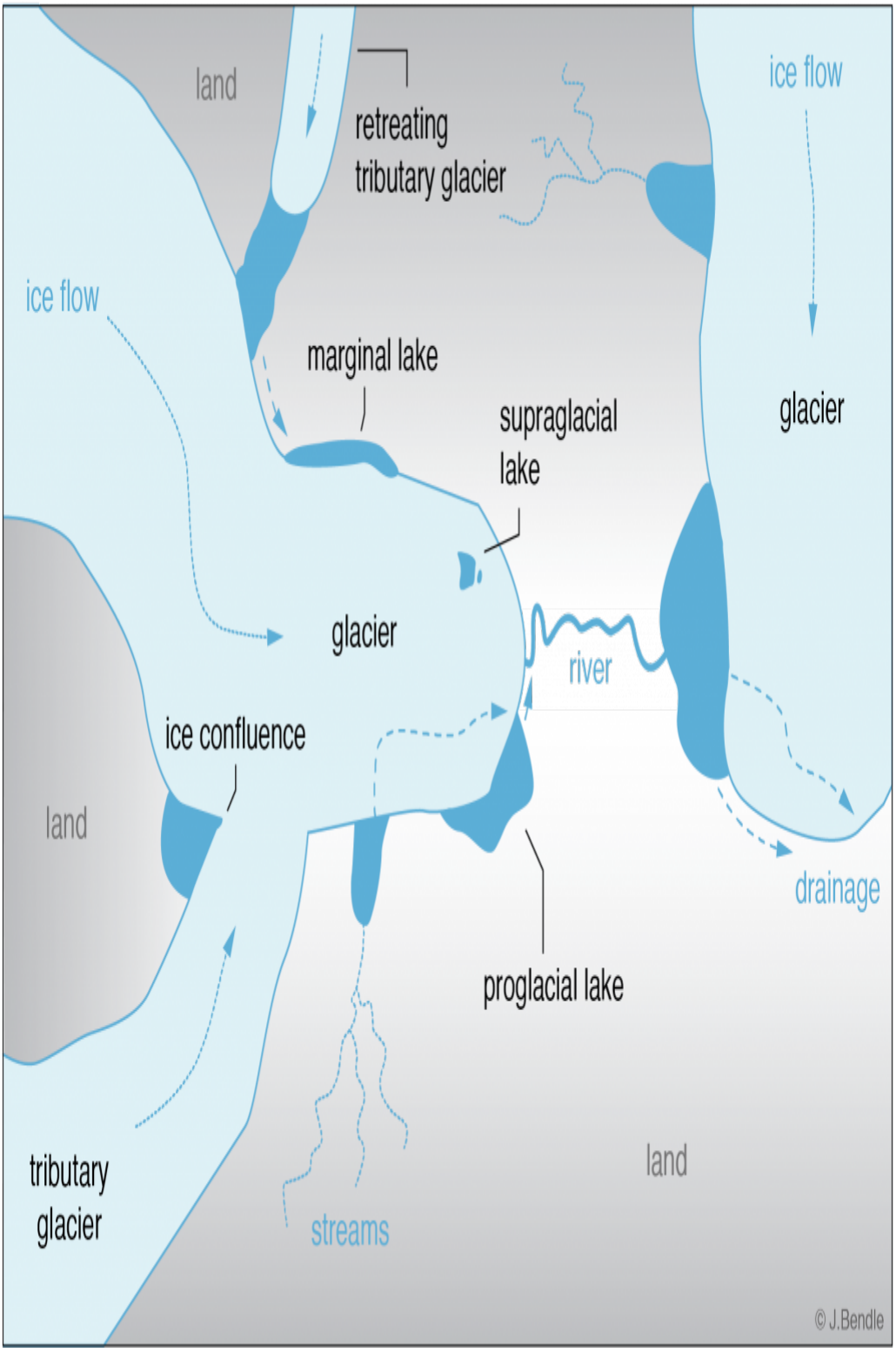


Figure 3: Ice-dammed lakes form where glaciers block the flow of water in either a trunk or tributary valley. Credit: Jacob Bendle.

Ice-dammed glacial lakes form whenever glacial ice blocks the drainage of rivers or meltwater, causing pooling [10] as well as through surge activity [11]. There are thousands of examples found across glaciated regions, for instance, the Merzbacher Lake, Kyrgyzstan and the Kyagar Tsho lake located in the Yarkant river basin in China.

Ice dammed lakes formed by surge activity such as the Kyagar Tsho lake usually survive or a few months to one year, with most draining soon after formation or leading to outburst.

See this post for further details.

Bedrock and landslide dammed glacial lakes

Due to glacial recession, areas that have been overdeepened by glacial-bed erosion can become exposed. Eventually, meltwater accumulates in place of the retreating glacier termini and forms more stable lakes known as bedrock-dammed lakes [13]. These lakes are different from moraine dammed lakes in that they are bound only by bedrock. See figure 4 below to illustrate of their formation.

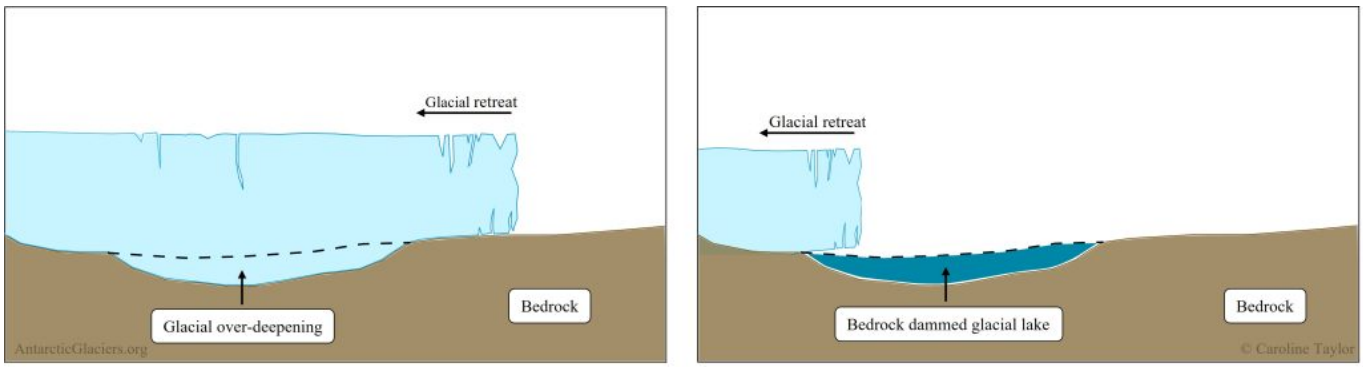


*Figure 4: Diagram to illustrate the formation of bedrock dammed glacial lakes. Glacial ice retreats to reveal an over-deepening in the bedrock, which then fills w*ith meltwater *to create a glacial lake. Credit: Caroline Taylor*

Unlike bedrock dams that form in existing depressions, landslide-dammed glacial lakes encompass all those impounded by new deposits due to slope movement, including landslides, rockslides/avalanches and debris-flows behind which glacial meltwater can accumulate [11]. Similar to ice-dammed lakes formed through surging, these type of lakes are often transient due to poor cohesion of the damming material, leading to rapid erosion and lake drainage [12].

Supraglacial lakes

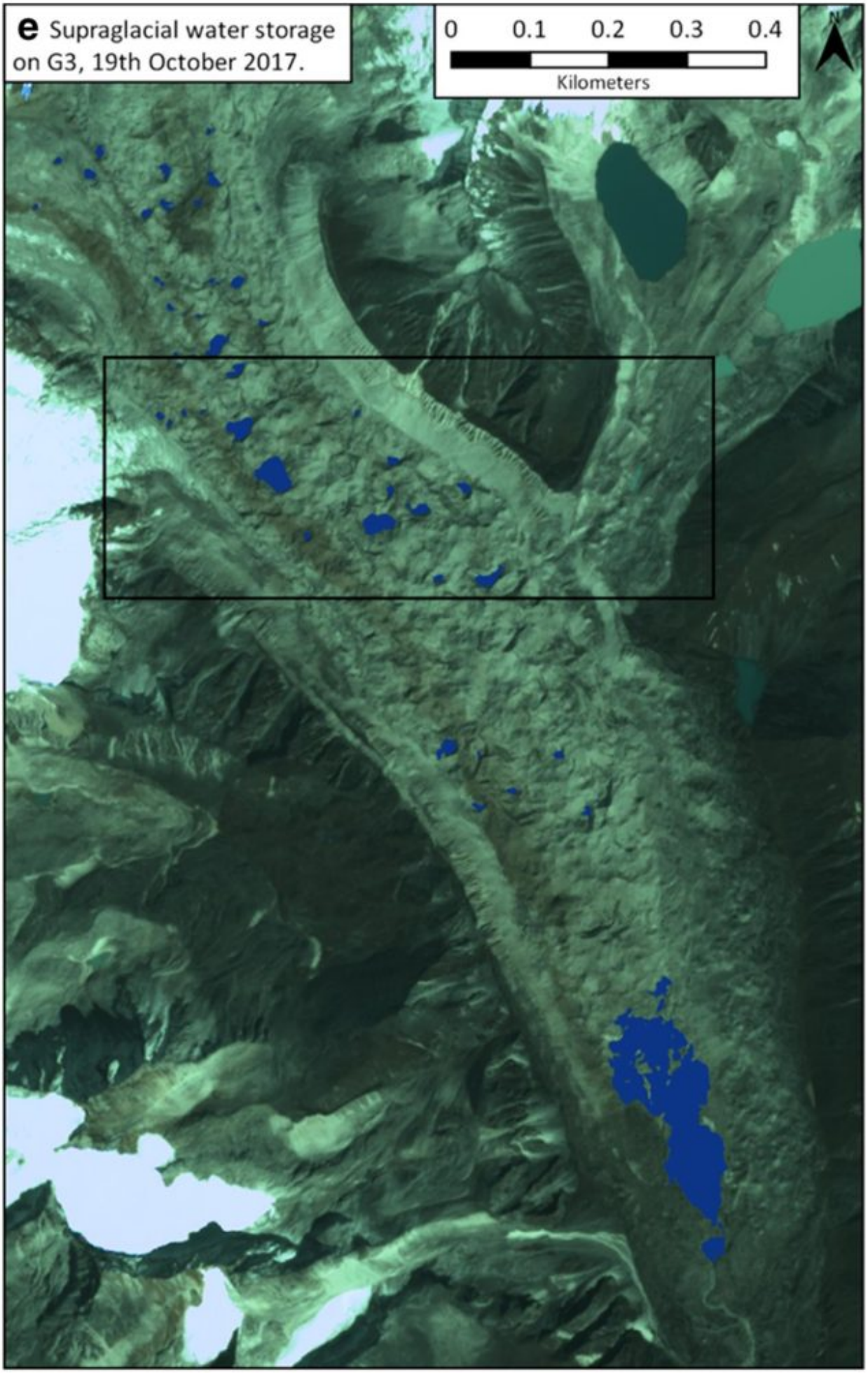

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Figure 5: Examples of supraglacial lakes on the surface of a glacier in Bhutan. Credit: Taylor et al., 2021.

Supraglacial lakes are water bodies on the surface of glaciers, generally caused by ablation [6]. Consequently, they are most commonly located in the ablation zones of debris-covered glaciers, such as those shown in figure 5.

As a glacier moves, supraglacial ponds can become connected to the englacial system, and thus can go through cycles of draining and refill [15].

Subglacial lakes

FUN FACT: A recent study by Livingstone et al. (2022) identified 773 subglacial lakes globally. Specifically they found 675 in Antarctica, 64 in Greenland, 6 in Iceland, 2 in the Devon Ice cap and 26 in valley glaciers.

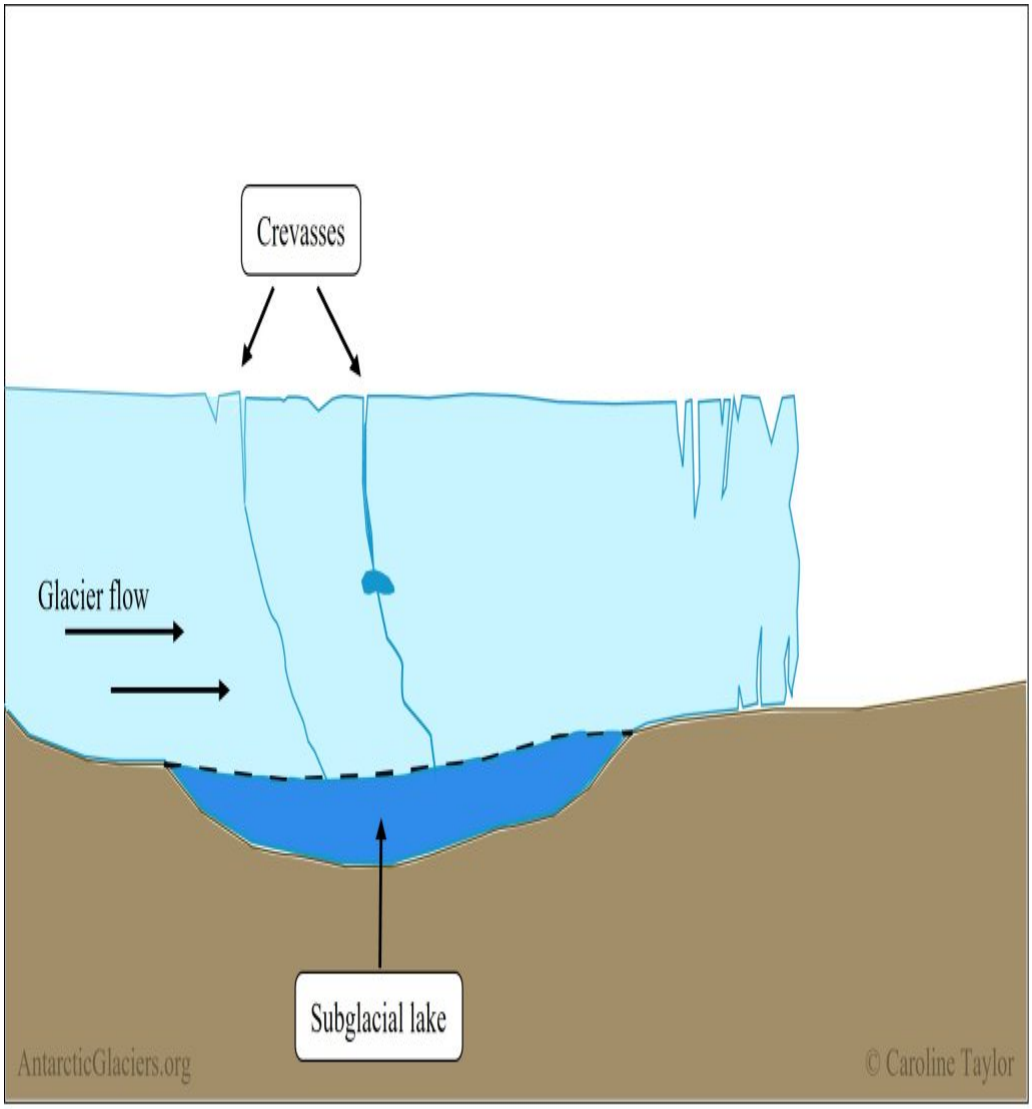

Figure 6: Schematic to illustrate the formation of subglacial lakes, forming at the base of a glacier and fed by englacial meltwater. Credit: Caroline Taylor.

Finally we have subglacial lakes, forming beneath glacial ice where there is no gradient for fluid potential [14]. In short, water is routed from the glacier surface englacially to the base, where it collects to form a subglacial lake (see figure 6 to illustrate their formation).

Given that subglacial lakes cannot be identified through satellite imagery, the most compelling evidence for their existence is Jökulhlaups.

See this post for an in detail example of the 1996 Grímsvötn outburst from the subglacial lake.

Summary

To sum up, glacial lakes play an important role on the cryosphere, are indicators of climate change and also represent glacial hazards. Due to the unique environments in which glaciers exist, there are several types of glacial lakes that can be found across the globe, as shown above. Because glacial lakes are so widespread, understanding the formation of these glacial features is vital not only if we are to avoid any major lake-related disasters but also to forecast where future lakes might develop.

References

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