MANAGEMENT OF NATURAL HAZARDS
IN MOUNTAIN BASINS

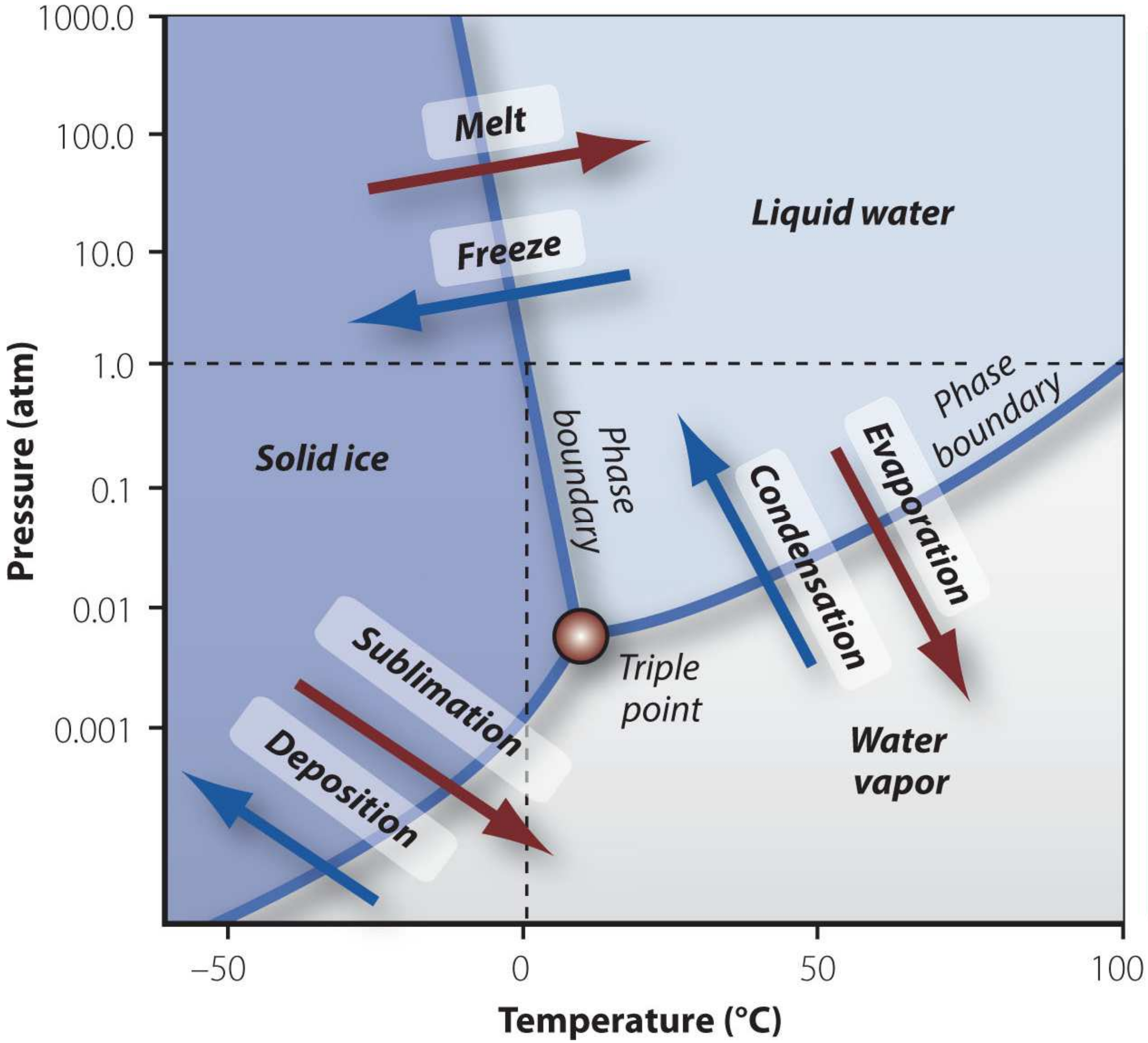
Glacial and periglacial processes and related hazards

Dr. Francesco Comiti
Academic year 2014/2015

Credits to:
P.R. Bierman, D.R. Montgomery (2014) «Key concepts in Geomorphology»

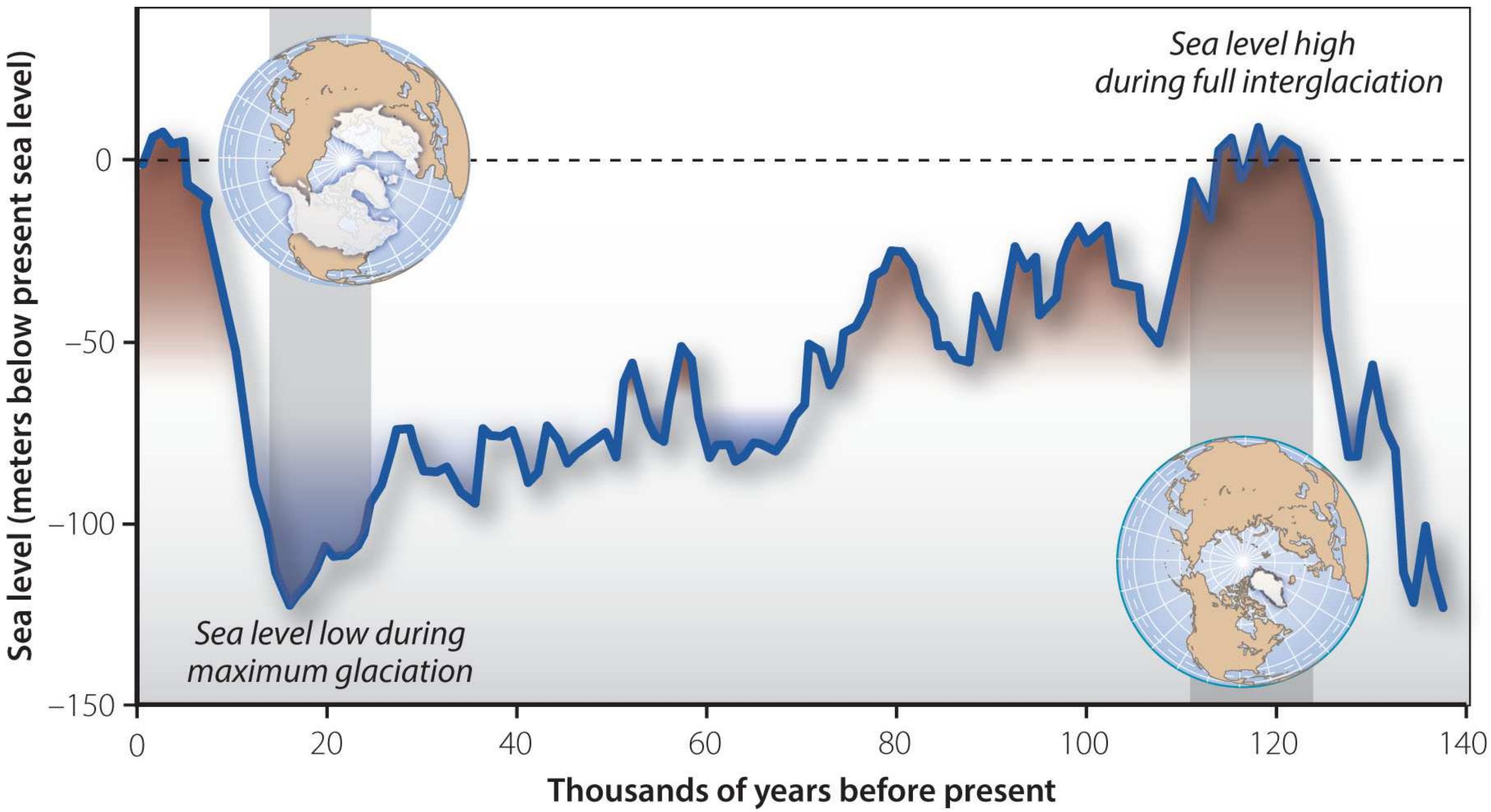
Why is ice important for Earth processes ?

- The phase diagram of water



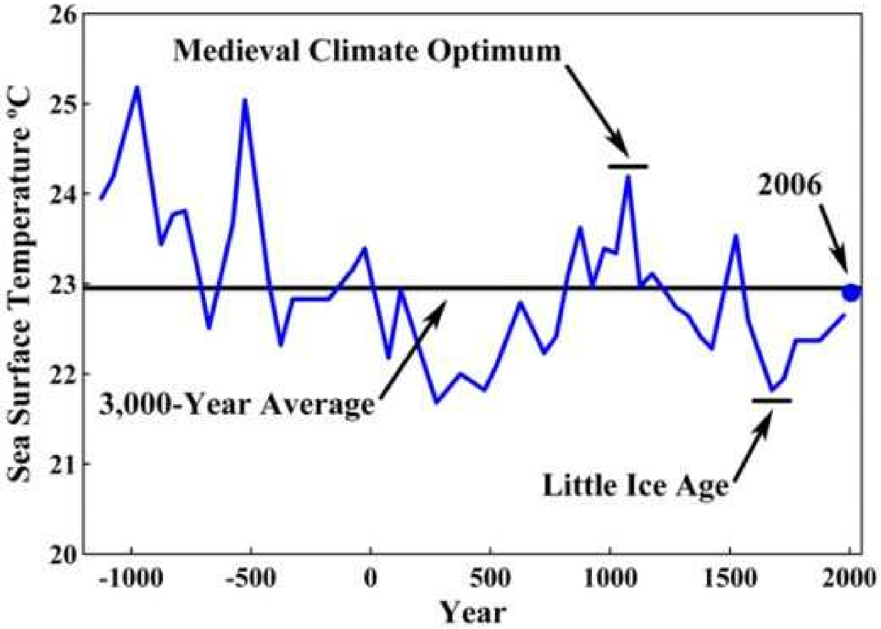
Water is unusual because, in the range of temperatures and pressures common on Earth's surface, it can exist in the vapor, solid, and liquid phases. The negative slope of the **phase boundary** between liquid water and ice means that as pressure increases, solid ice, kept at a steady temperature, will melt—a phenomenon referred to as **pressure melting.** The triple point is the pressure and temperature condition at which all three phases of water coexist.

Climate oscillations during the last 140 kA



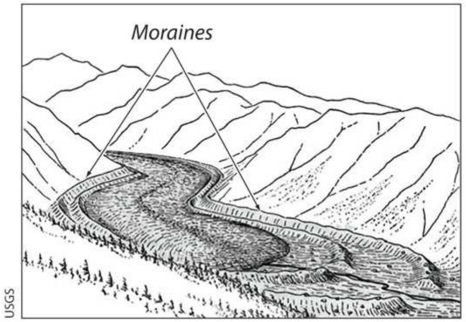
As ice sheets grow, they lock up water that otherwise would fill the ocean basins. During glaciations, sea level falls proportional to the amount of water stored in ice caps and glaciers. During interglaciations, sea level rises as ice caps and glaciers shrink and meltwater returns to the oceans.

Recent climate oscillations

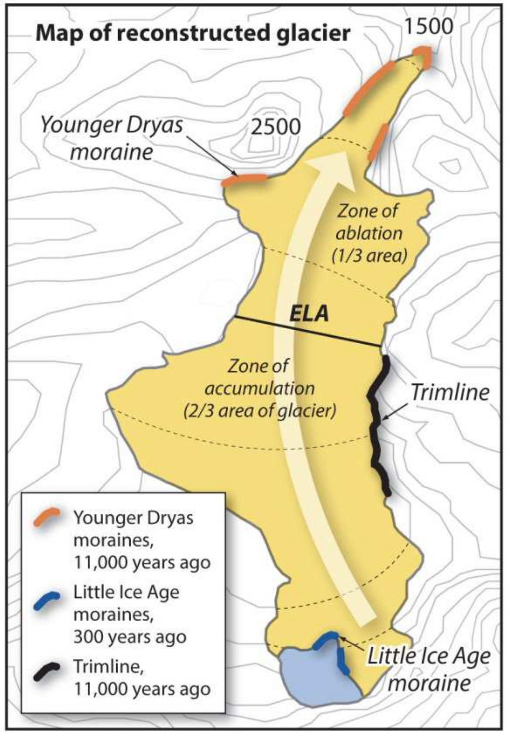


From Zebisch & Niedrist (2011

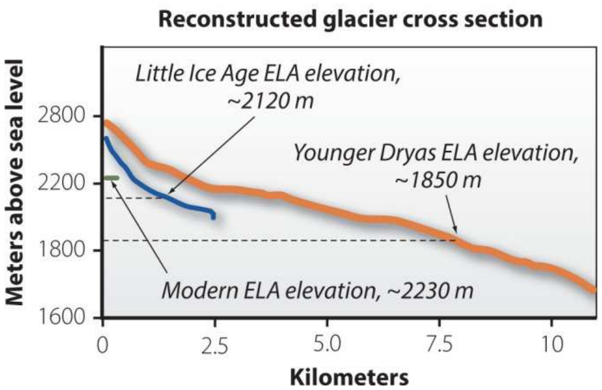
Remnants of the past glacial periods



Alpine **moraines** can be mapped in the field and used to define the down-valley extent of now-vanished glaciers. Moraines, which are built by deposition of material from melting ice, are found only in the ablation zone. In the accumulation zone, ice extent is defined by the extent of glacially polished rock and trimlines where weathered rock has been removed by glacial erosion.

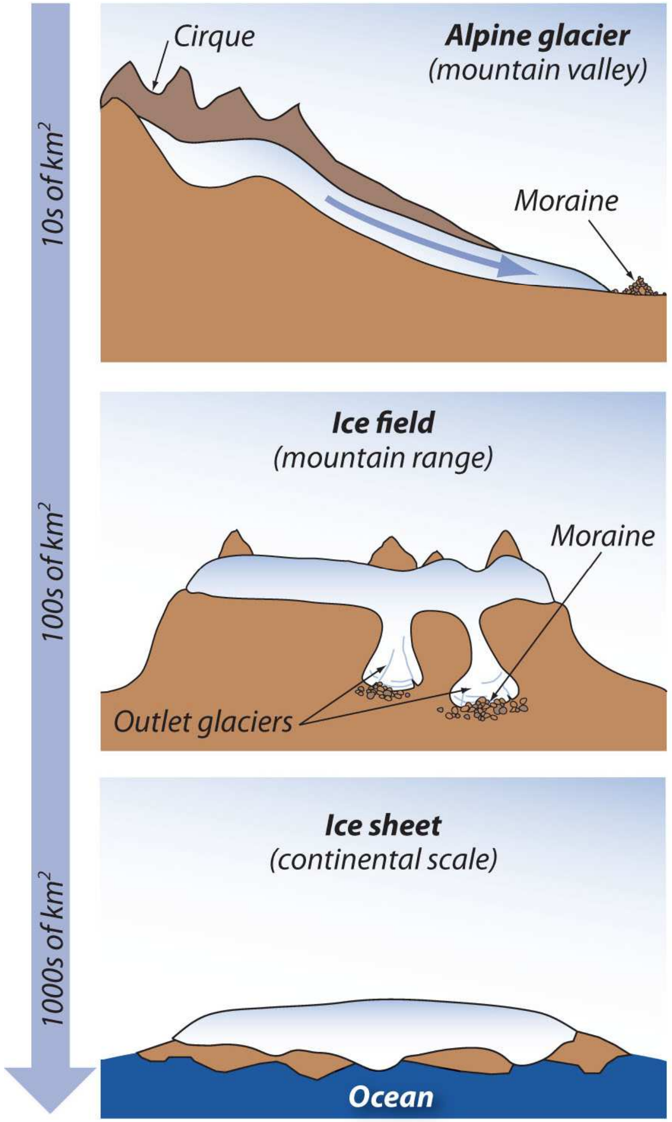


Using a topographic map and the location of mapped moraine segments and trimlines, one can sketch the outline of the glacier that once filled the valley. Empirical studies have shown that, on average, about 2/3 of an alpine glacier's surface area lies in the **accumulation zone** and 1/3 lies in the **ablation zone.** Using this **accumulation area ratio** (AAR) of 2/3, one can define the former equilibrium line altitude or **ELA,** the boundary between the accumulation and ablation zones. The surface of the reconstructed glacier can be contoured. In the accumulation area, the contours are convex up glacier because ice flow is convergent. In the ablation zone, the contours are convex down glacier because the flow is divergent. You can create a cross section of the vanished glacier using the contour map-based glacier reconstruction.



During the Younger Dryas cold period between about 12,800 and 11,500 years ago, the ELA in the Alps fell almost 400 m below its elevation today. During the Little Ice Age (between 1300 and 1850 CE) , the ELA dropped 110 m from today's elevation of 2230 m. Assuming that ELA changes reflect only cooling, and considering a lapse rate of 1° C per 100 m elevation, the Little Ice Age was about a degree cooler than today. Younger Dryas times were about 4° C cooler.

Glacier types on Earth



M. Geilhausen

Alpine glaciers are topographically constrained by the cirques in which they originate and the valley walls that confine them. Lower reaches of alpine glaciers are often bordered by moraines.

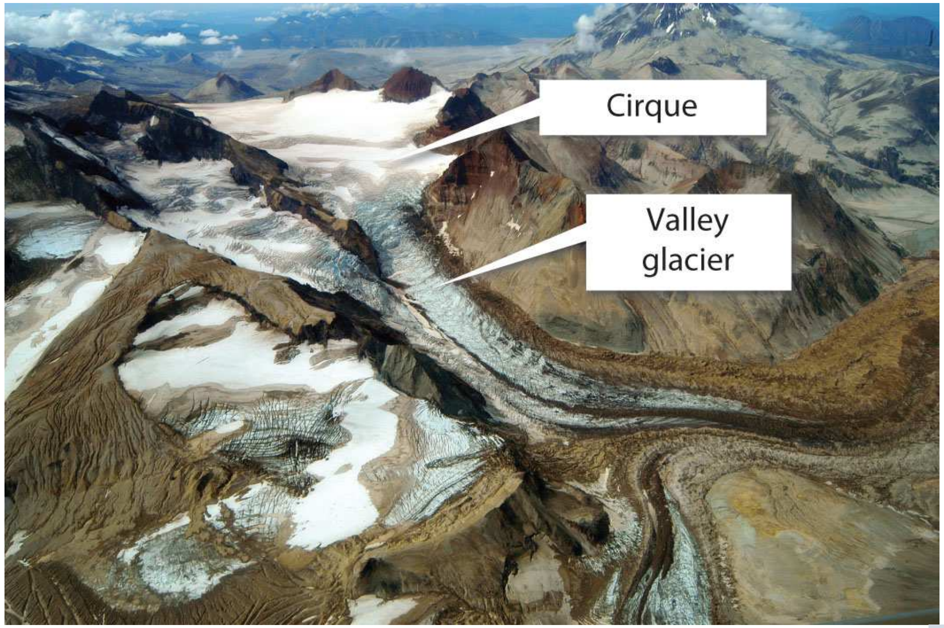
NASA

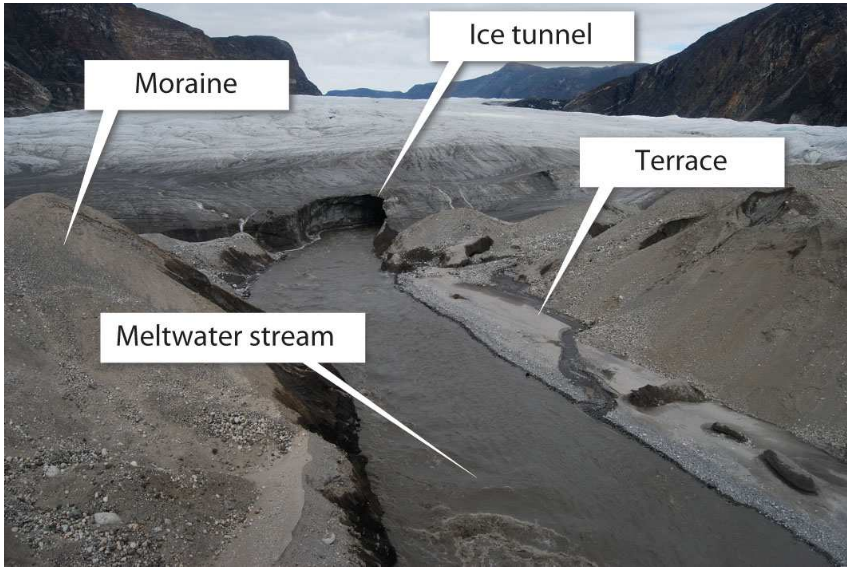
Ice fields occupy highlands and in many places bury existing topography. They are drained by outlet glaciers that transport ice to lower elevations where it melts and deposits moraines.

P. Bierman

Ice sheets largely overwhelm topography, ice buries peaks, and the surface slope of the ice sheet controls ice flow direction. Ice sheets deposit moraines and other glacial sediments.

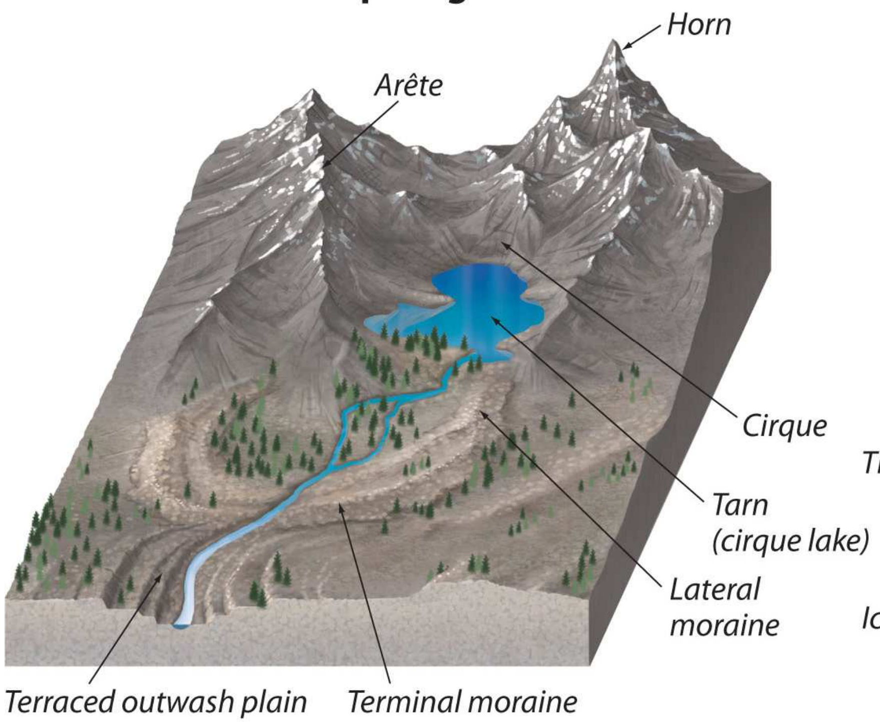
Glacier types on Earth





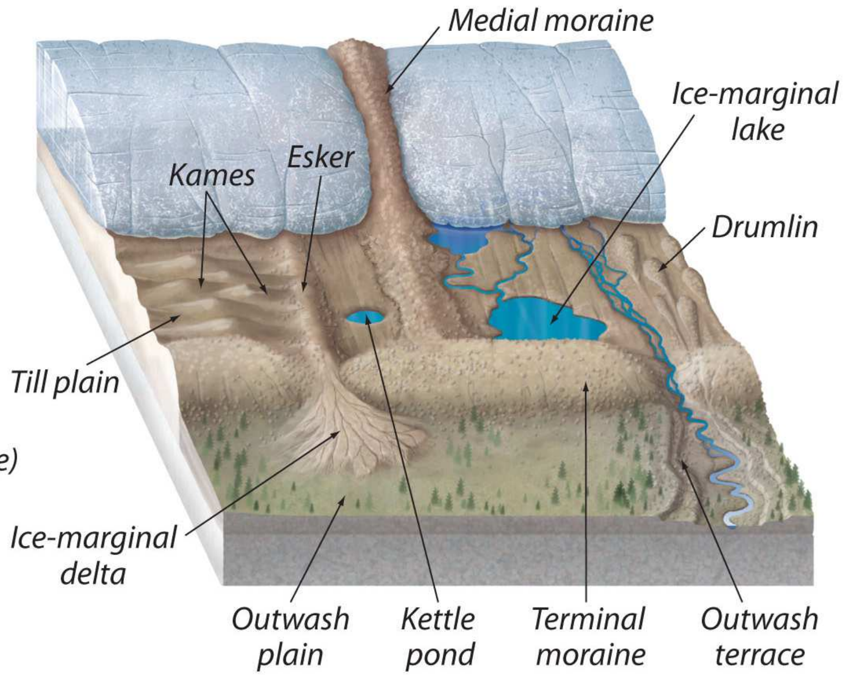
Effects of glaciation

Alpine glaciation



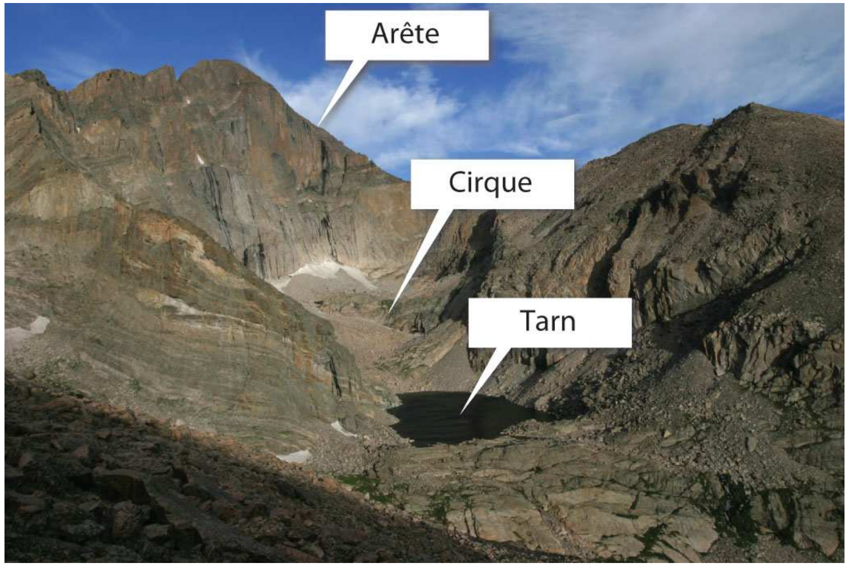
Alpine glaciation leaves a distinctive character to the landscape, including erosional landforms such as **cirques, arêtes, tarns,** and **horns,** as well as depositional features including both lateral and terminal **moraines** and **outwash terraces.** A complex series of moraines can record episodes of glacial advance and retreat.

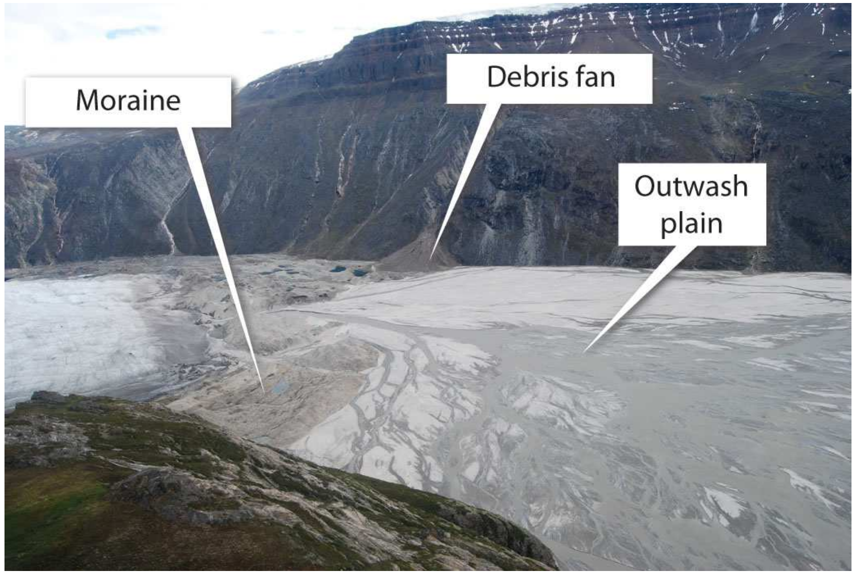
Continental glaciation

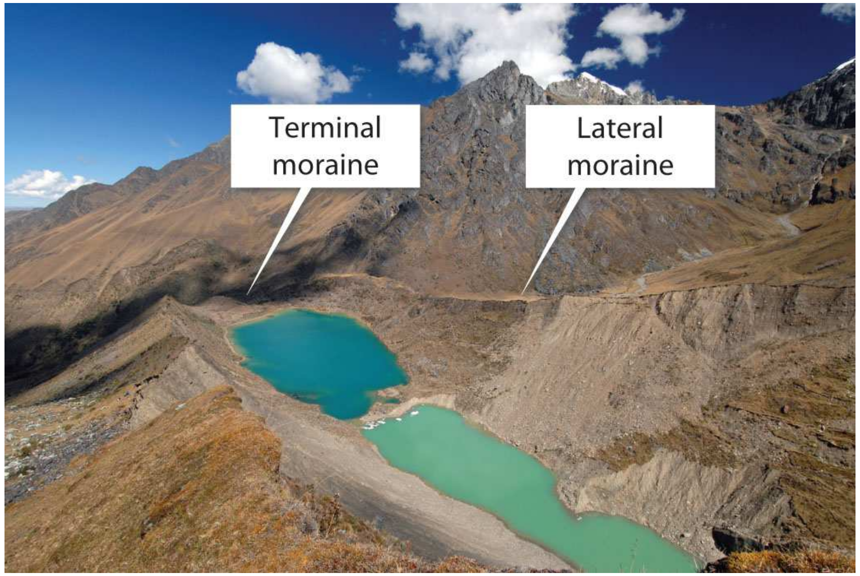


Continental ice sheets leave distinctive landforms, including moraines, ice-marginal lake deposits such as **deltas, outwash terraces, kames, eskers,** and **kettle ponds. Till plains** cover much of the area once occupied by continental ice; in other areas, streamlined forms such as **drumlins** dominate. Outwash plains and terraces form outside the ice margin.

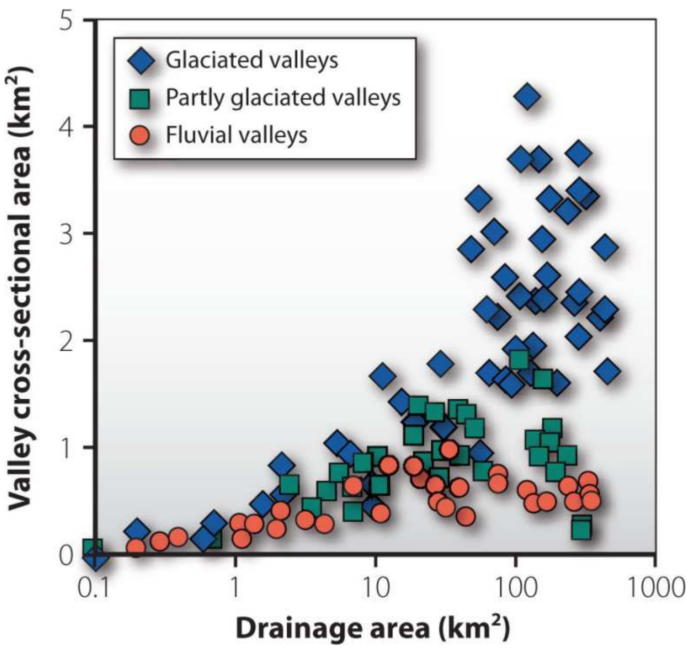
Effects of glaciation

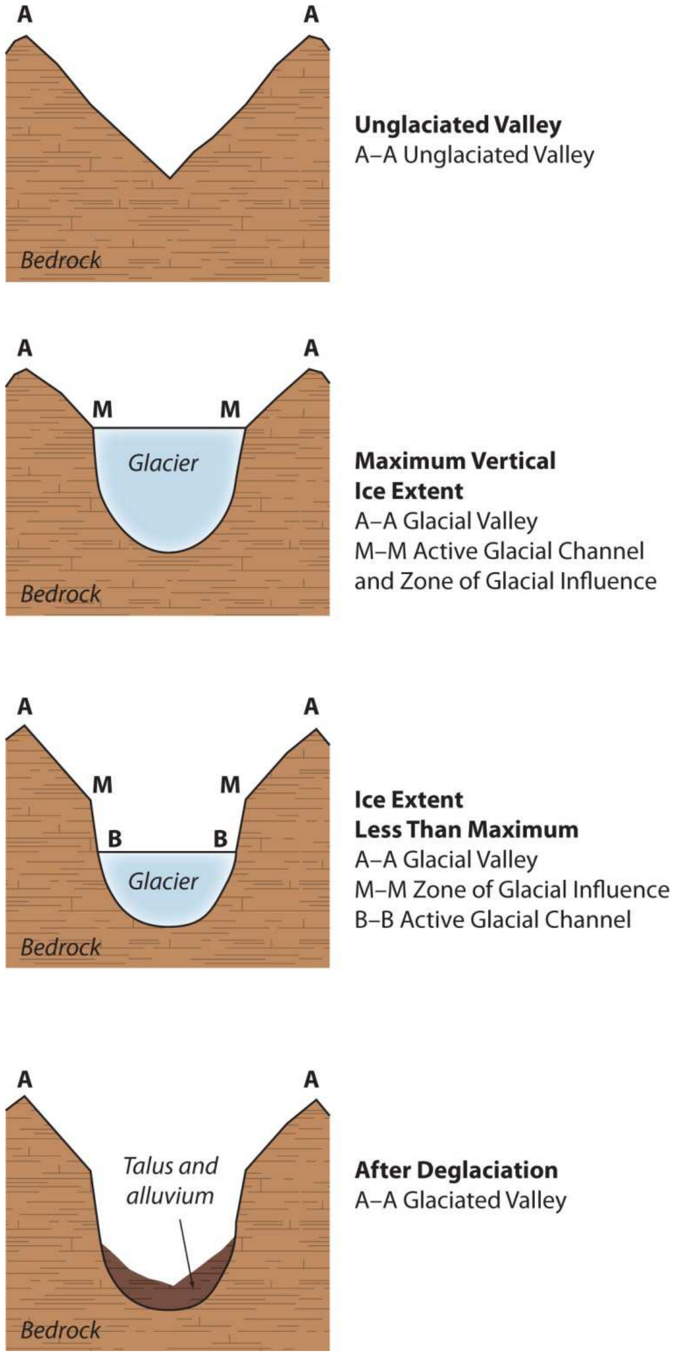




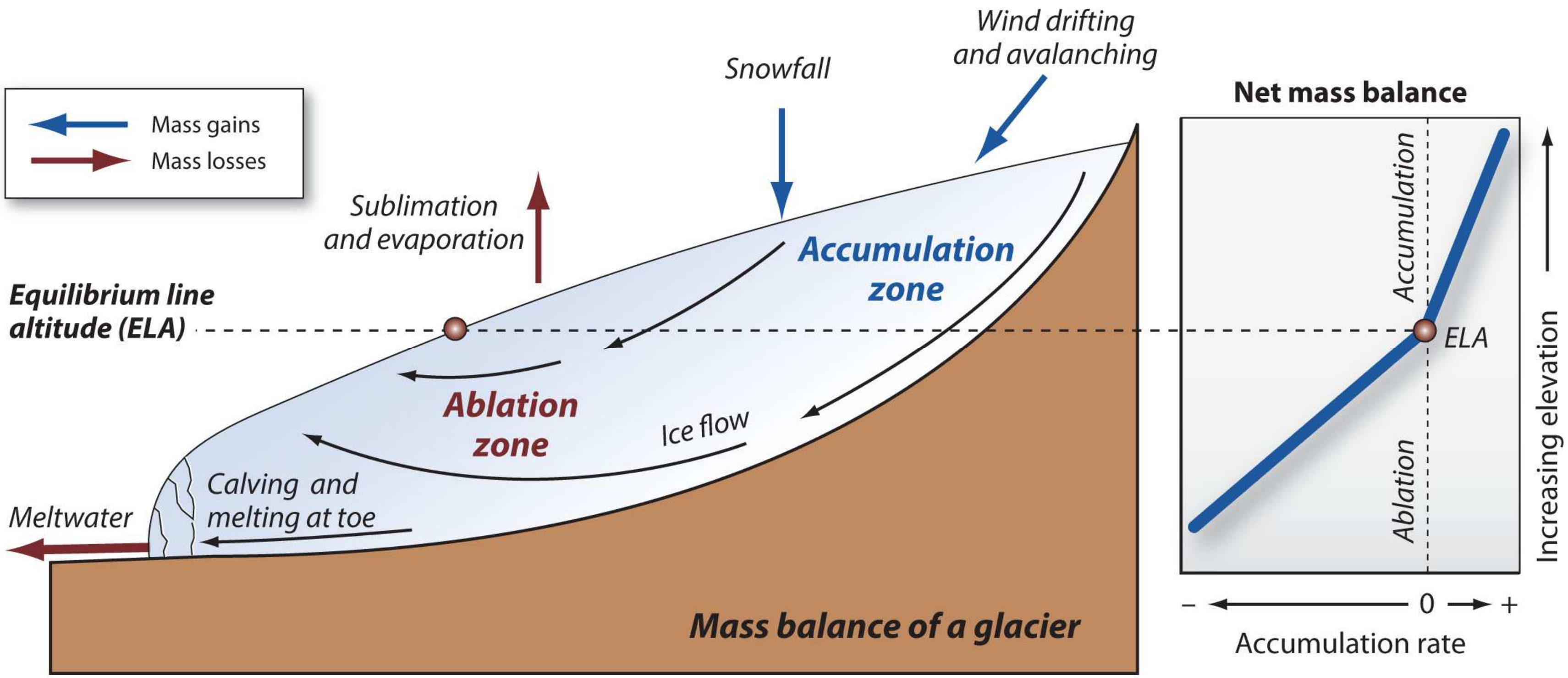


Effects of glaciation



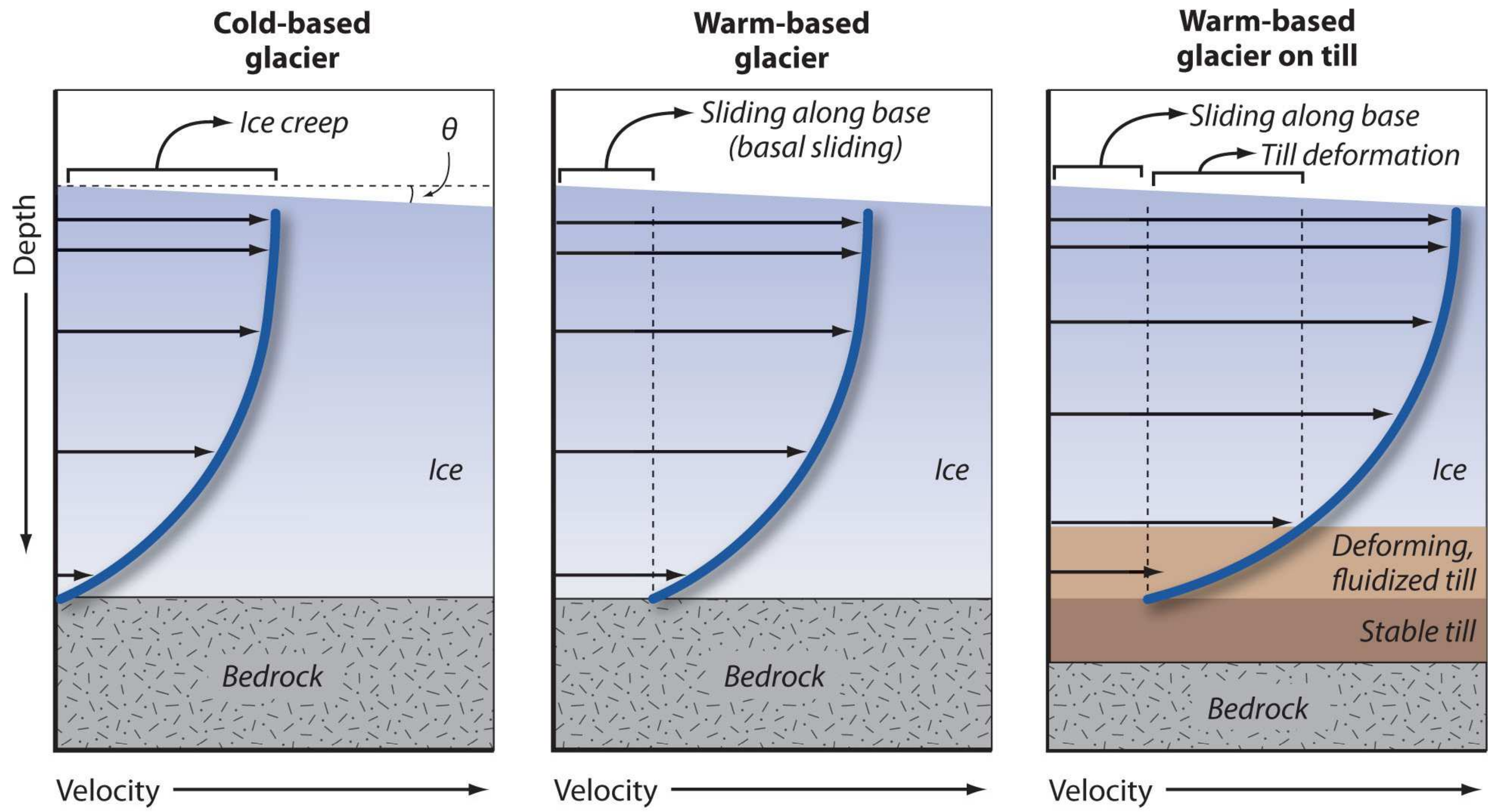


Glacier mass balance



Mass balance is critical to glacier persistence and size. In the **accumulation zone,** more frozen water is deposited (by snowfall, wind drift, and avalanching) than melts away. This excess mass flows as glacial ice into the **ablation zone,** where it leaves the glacial system by melting, sublimation, and calving. In the ablation zone, there is net mass loss. The **equilibrium line** separates the accumulation and ablation zones. Its elevation is similar to the end of summer snow line and the elevation where, in the northern hemisphere, the average July temperature is about 0°C. If the ELA does not change over time, the glacier is in steady state and its mass balance is stable. However, if the ELA rises, the glacier will lose mass and retreat; if the ELA lowers, the glacier will gain mass and advance.

Glacier type and flow dynamics

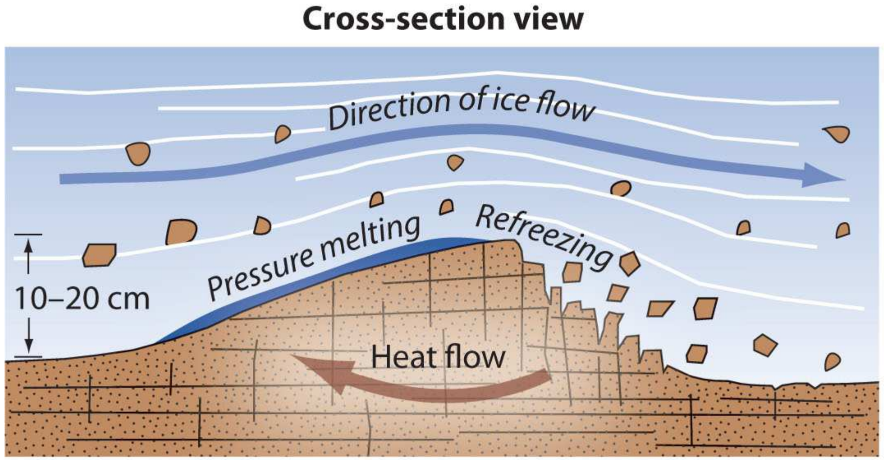


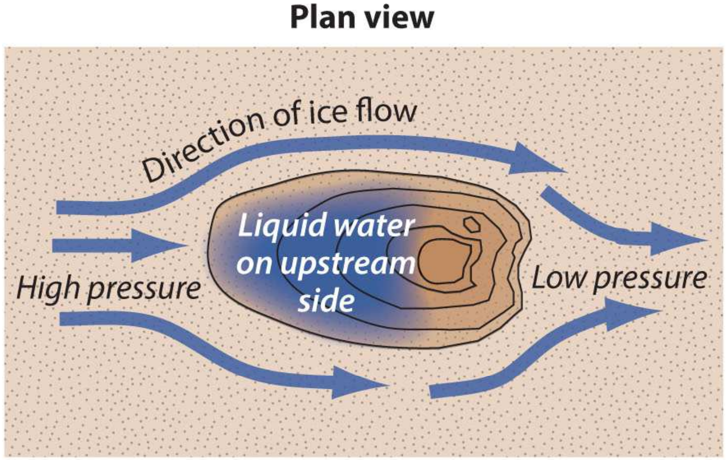
Cold-based ice is frozen to the bed. Ice movement is driven by deformation (creep) of the ice driven by the ice surface slope θ. Creep rates of ice are slow.

Warm-based ice is not frozen to the bed and thus can slide over the bed in addition to deforming internally. Ice can move quickly by sliding, especially in summer when there is more meltwater.

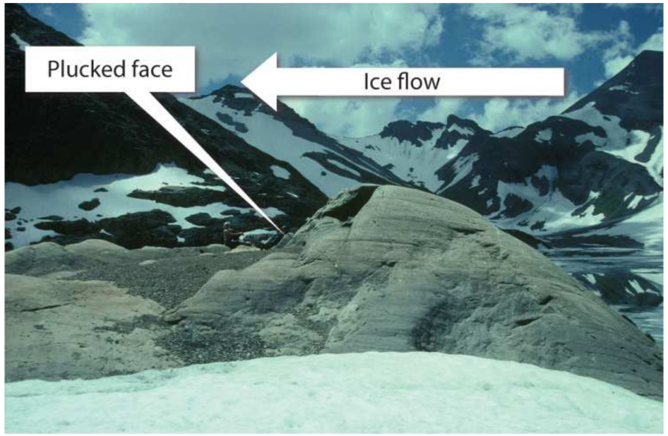
Some warm-based ice not only slides over the bed and deforms internally, but is underlain by mobile deforming till above undeforming, stable till.

Glacier flow dynamics and erosion action





Regelation occurs when ice flows over rock obstacles on the glacier bed. Pressure-melting of ice up-glacier of an obstacle releases water, which then travels down ice to areas of lower pressure and consequently refreezes. This refreezing may incorporate debris and enrich the remaining solution in elements such as calcium, which precipitates and forms calcium carbonate coatings on subglacial rock surfaces. Regelation facilitates the movement of warm-based glacial ice over rough bedrock beds.

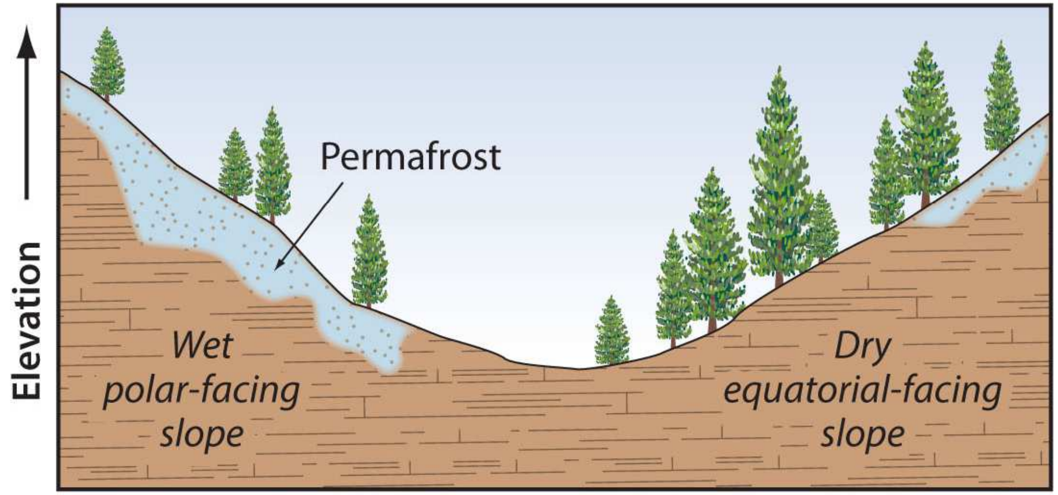


Permafrost

- Ground frozen for at least two years

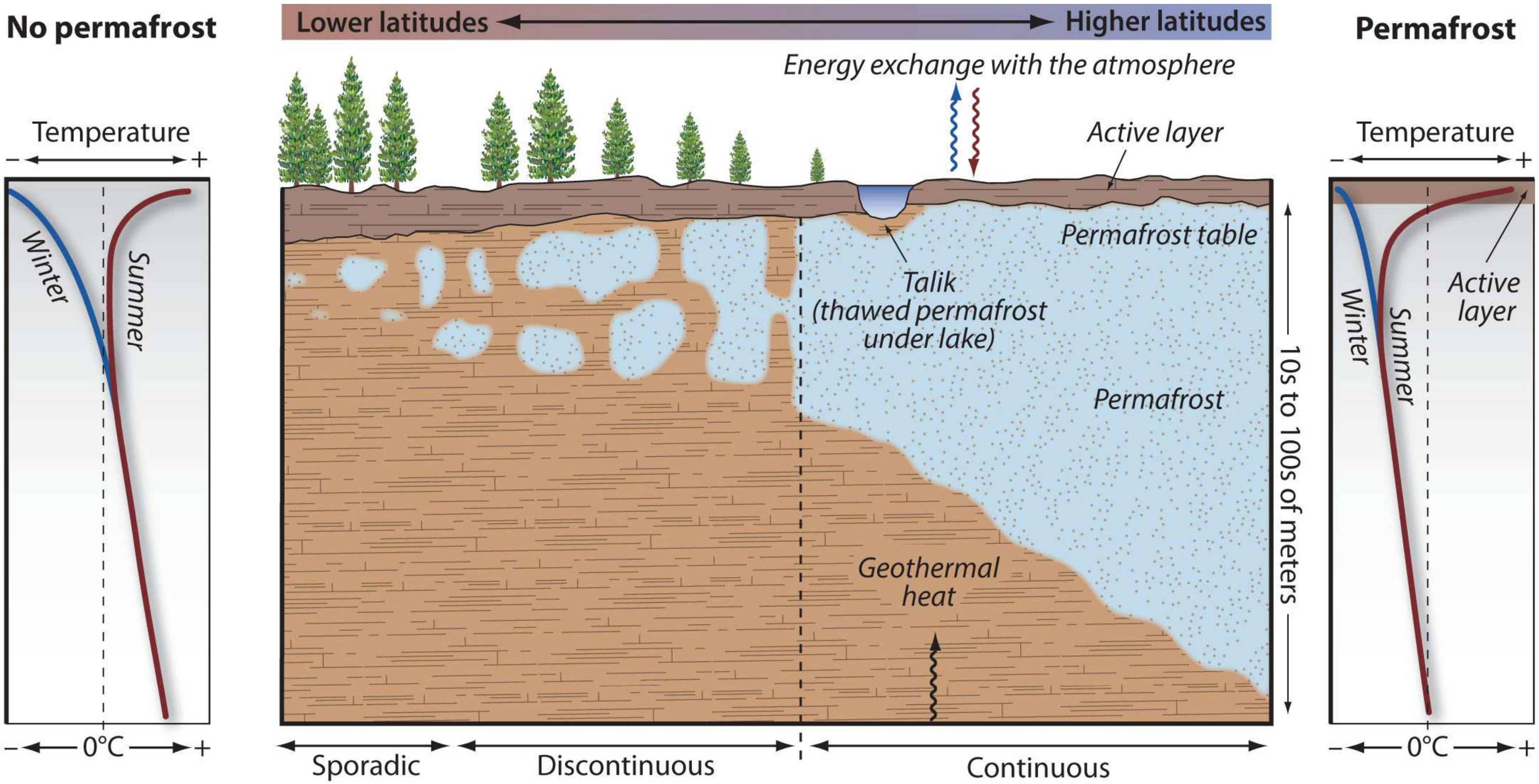
- High elevation or high latitudes

Permafrost distribution is controlled by climate, most importantly mean annual air temperature. In continental areas of Eurasia, far from warm oceans, permafrost is found farther south than in areas near the relative warmth of the ocean. Permafrost also occurs at high altitudes (such as the Tibetan Plateau) because mean annual air temperature decreases with elevation.



Aspect affects the amount of solar radiation a slope receives and influences the distribution of permafrost. Slopes facing the equator receive more sunlight, have less permafrost, and the permafrost they do have is found at higher elevations.

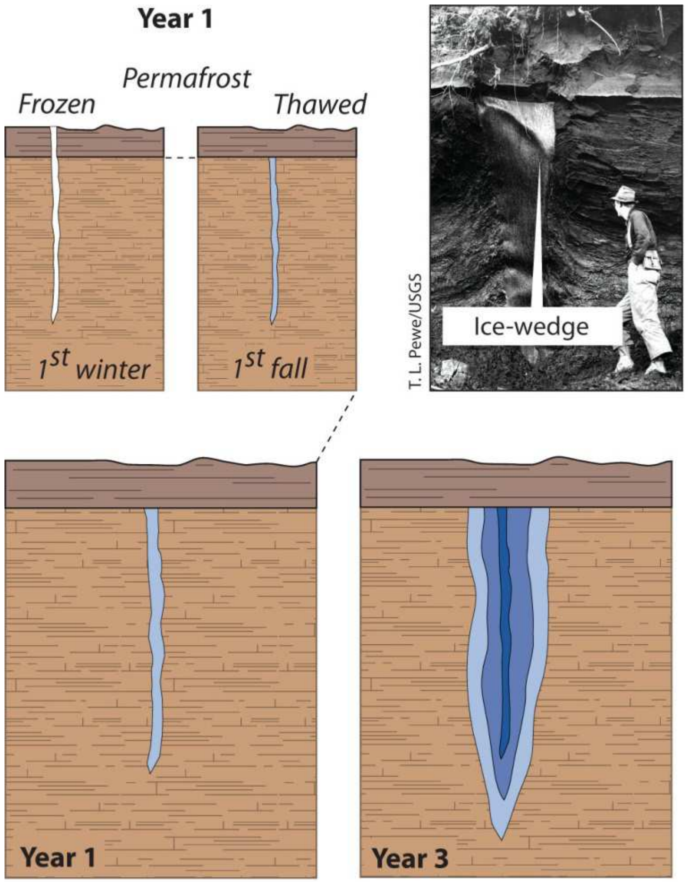
Permafrost

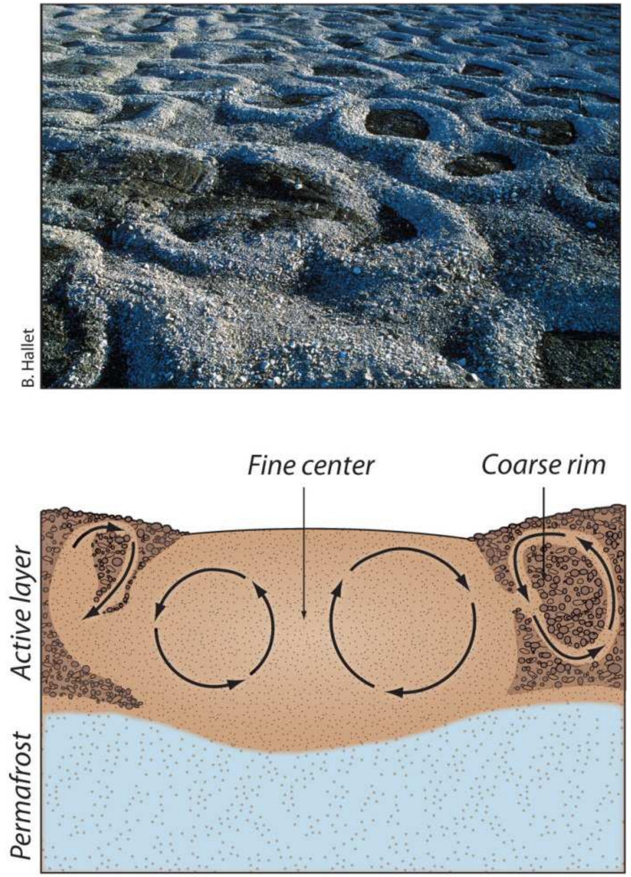


Permafrost can be continuous or discontinuous. Above the permafrost, the **active layer,** which is decimeters to meters thick, thaws every summer. Unfrozen material under the permafrost or within permafrost is known as a **talik.** Talik depths increase under lakes and rivers.

The temperature profile in the upper active layer of permafrost varies seasonally, freezing in the winter and thawing in the summer. Temperature in the permafrost generally increases with depth because of geothermal heat.

Permafrost: soil dyamics





Ice-wedges, soil cracks filled with ice, are diagnostic of permafrost. They form when the ground cracks and contracts as it freezes. After the active layer thaws the next summer, water fills the crack and freezes. As the cycle continues, year after year, the wedge grows. **Ice-wedge casts** indicate where permafrost used to exist. They form when ice melts away and sediment fills the resulting void.

Patterned ground, in this case, sorted circles, is a common permafrost feature. Field instrumentation and monitoring indicate that these circles result from slow soil convection (driven by temperature contrast) that sorts the coarse sediment from the fine sediment. Relict sorted circles are found in areas that were once cold enough to support permafrost but are too warm to do so today.

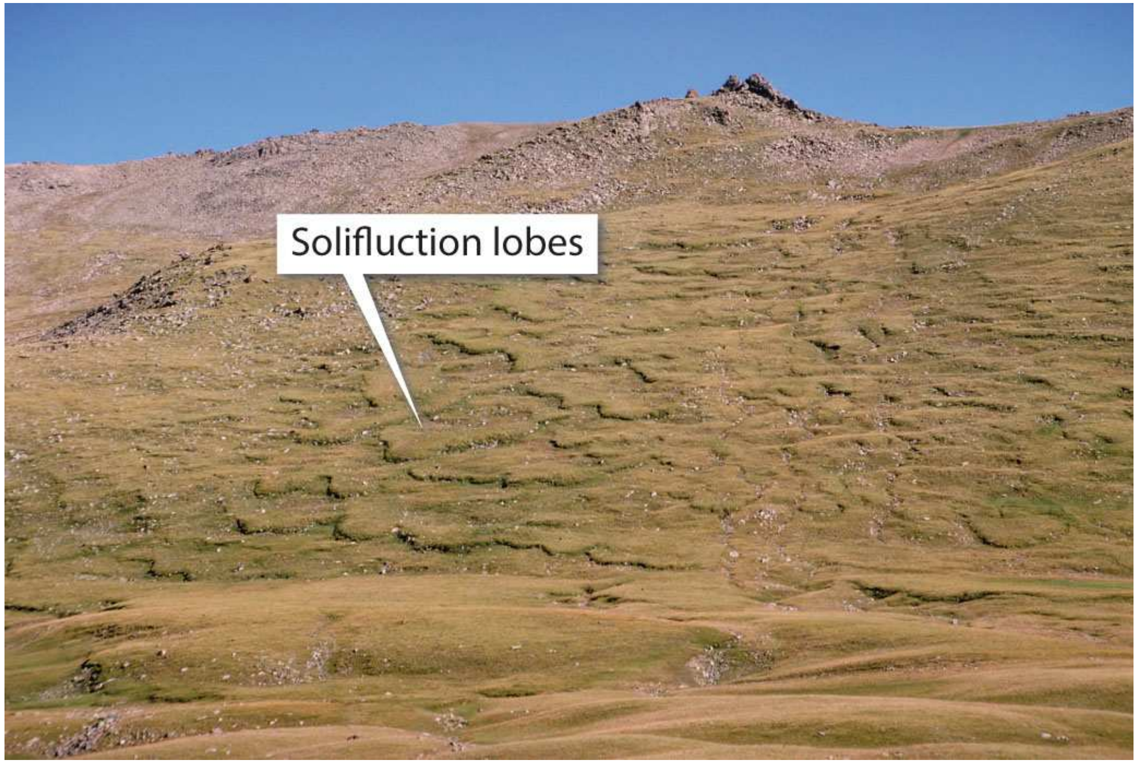
Permafrost: patterned ground

Permafrost: solifluction (gelifluction)

- Slow mass movement of soil and regolith affected by alternate freezing and thawing of the upper soil layer

- Characteristic of saturated soils at high latitudes/elevations

- Movements (slow) occur during the summer thawing of the upper layer overlying the permafrost

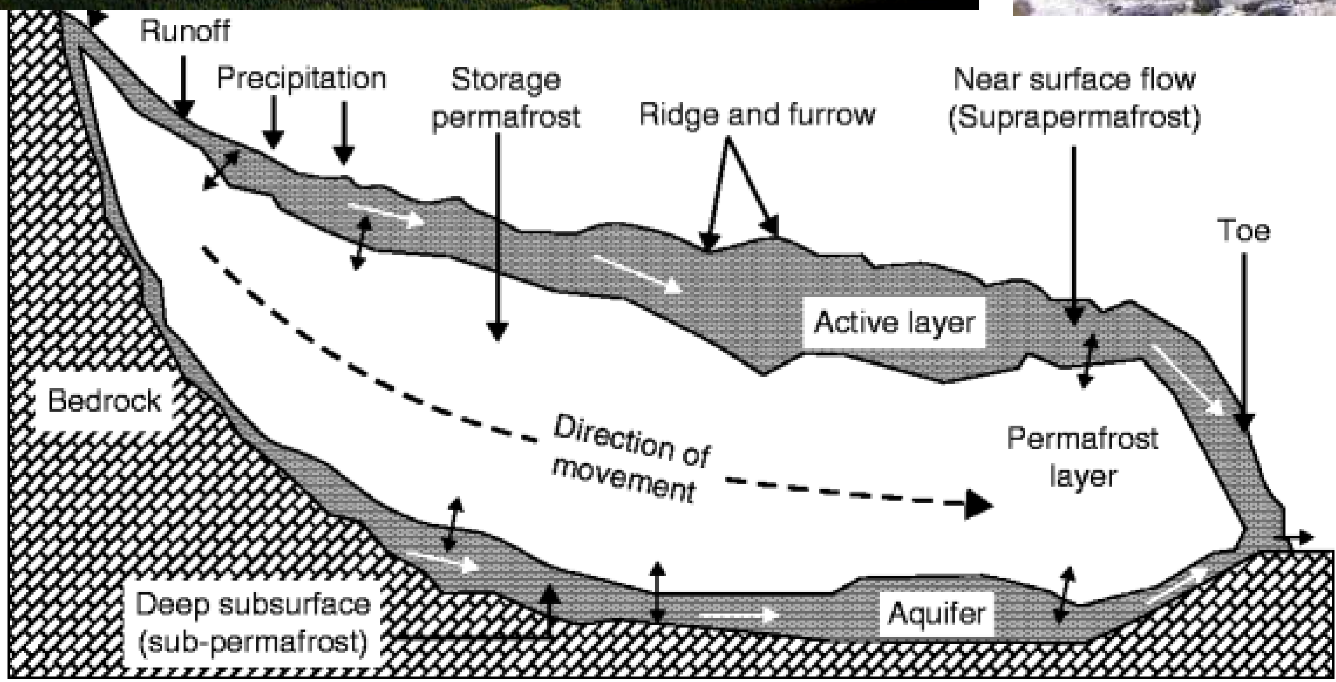


Rock glaciers

- Talus-derived rock glaciers (periglacial form): caused by continuous freezing occurring within a talus slope

- Glacial rock glaciers (glacial form): created by the recession of debris covered glaciers. As the glaciers shrink, their composition changes as they become increasingly covered with debris. Eventually, the glacial ice is replaced by ice cored rocks

Rock glaciers



Glacial and periglacial hazards

- Glacial
  - Glacier dynamics (for sky/tourism-related infrastructures)
  - Sudden collapse of seracs/icefalls
  - Glacial lake outburst floods (GLOFs)

- Periglacial
  - Solifluction (for infrastructures)
  - Rock glacier movements (for infrastructures)
  - Rapid mass movements due to permafrost reduction (loss of ice-related cohesion)
  - Long-term aggradation in the channel network for increased sediment supply

Glacial and periglacial hazards

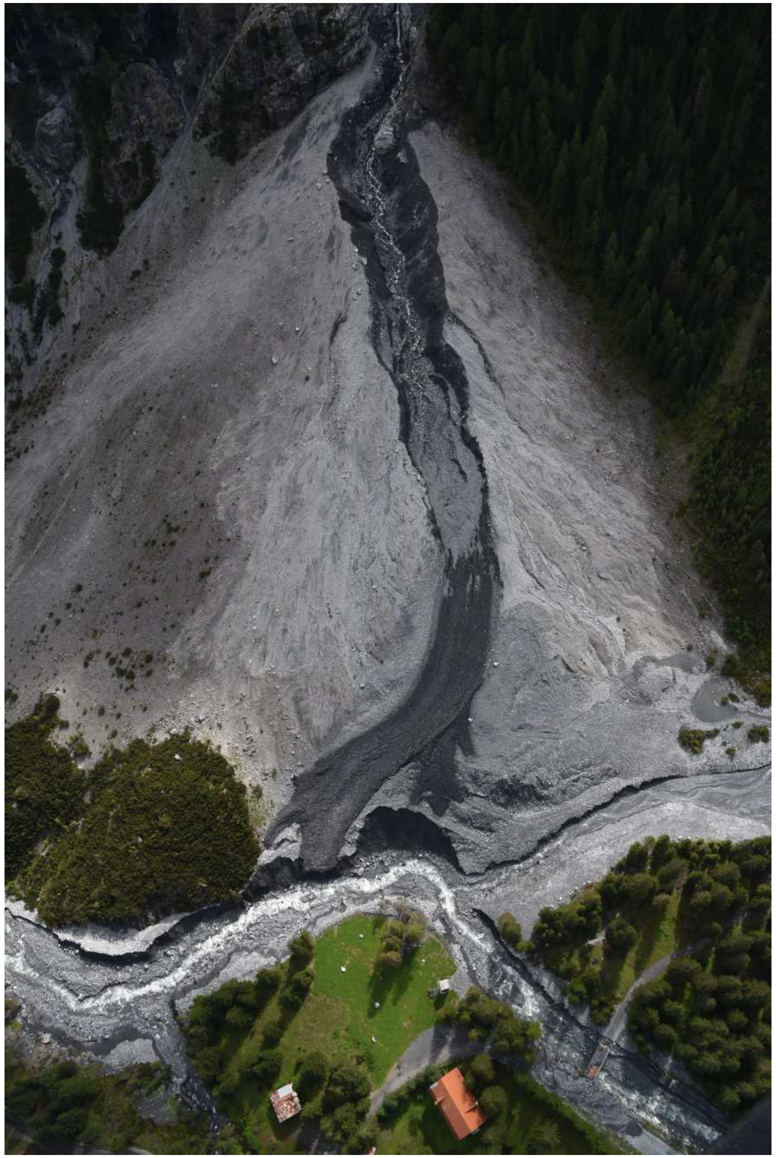
- Collapse of icefalls

Plaies (Trafoi, Bolzano, 2014)

Photos courtesy of the Provincia di Bolzano

Glacial and periglacial hazards

Photos courtesy of the Provincia di Bolzano



Glacial and periglacial hazards

- GLOF

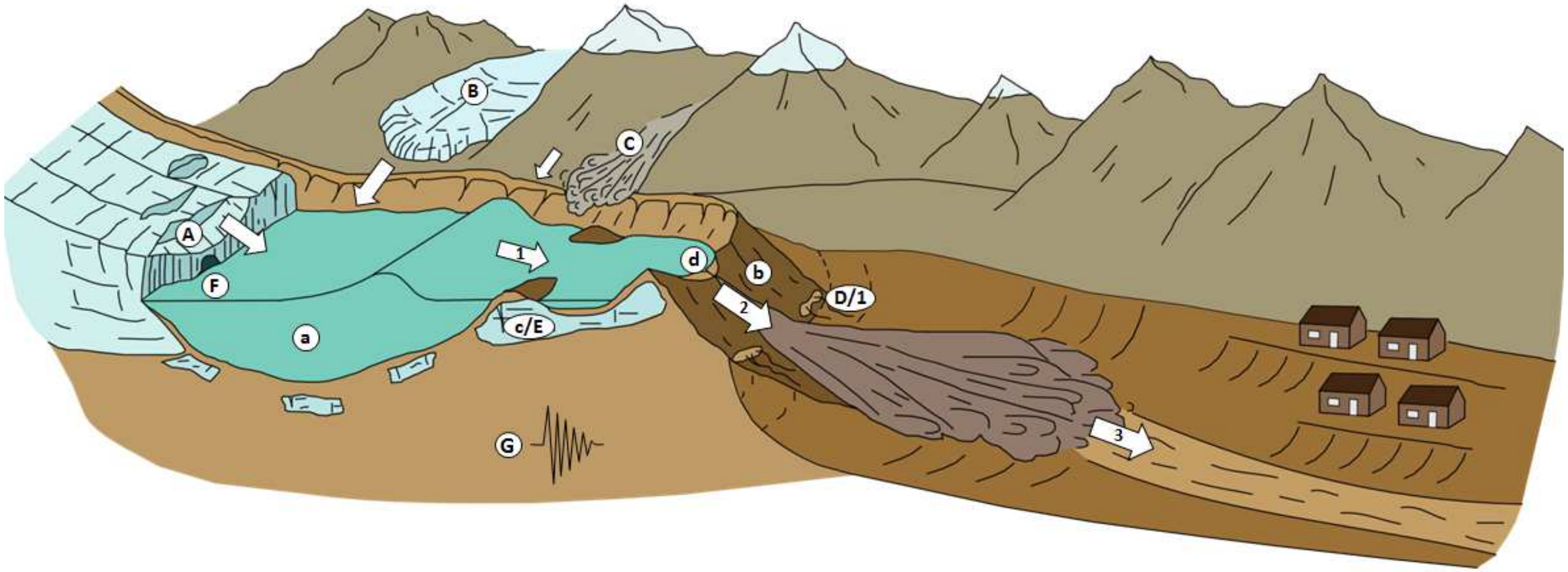
A type of outburst flood occurring when water dammed by a glacier or a moraine is released.

A water body that is capped by the glacier is called a sub-glacial lake. When a sub-glacial lake bursts, the event is sometimes called *jökulhlaup*.

- Frequent in Iceland and Himalaya

- Locally in the Alps

Glacial and periglacial hazards



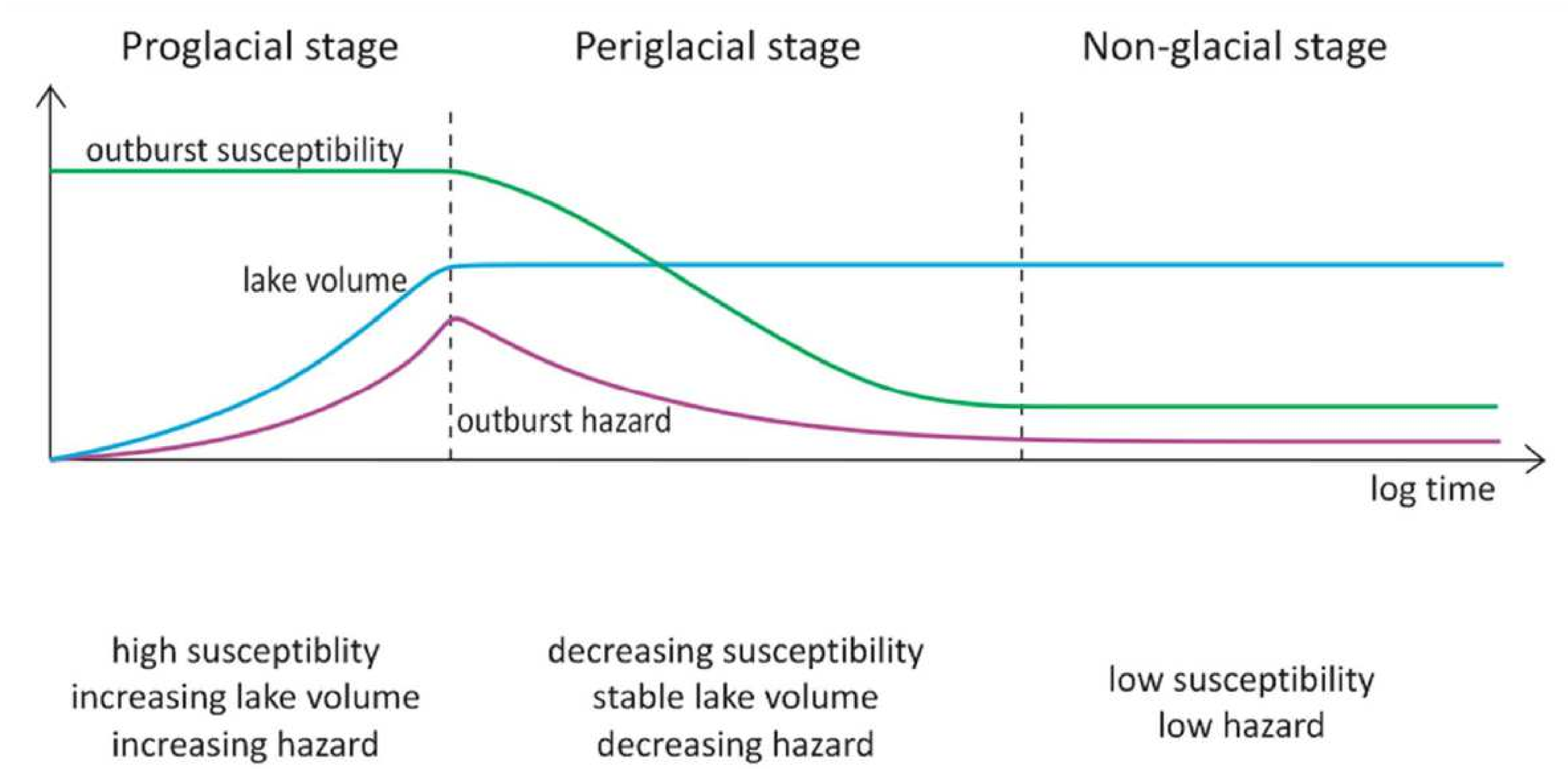
Potential triggers, conditioning factors, and key 'phases' in a GLOF event are highlighted. Potential triggers include: (A) contact glacier calving; (B) icefall from hanging glaciers; (C) rock/ice/snow avalanches; (D) dam settlement and/or piping; (E) ice-cored moraine degradation; (F) rapid input of water from supra-, en-, or subglacial (including subaqueous) sources; (G) seismicity.

Conditioning factors for dam failure include (a) large lake volume; (b) low width-to-height dam ratio; (c) degradation of buried ice in the moraine structure; (d) limited dam freeboard. Key stages of a GLOF include (1) propagation of displacement or seiche waves in the lake, and/or piping through the dam; (2) breach initiation and breach formation; (3) propagation of resultant flood wave(s) down-valley.

Adapted from Richardson and Reynolds (2000a) and Westoby et al. (2014)

Glacial and periglacial hazards

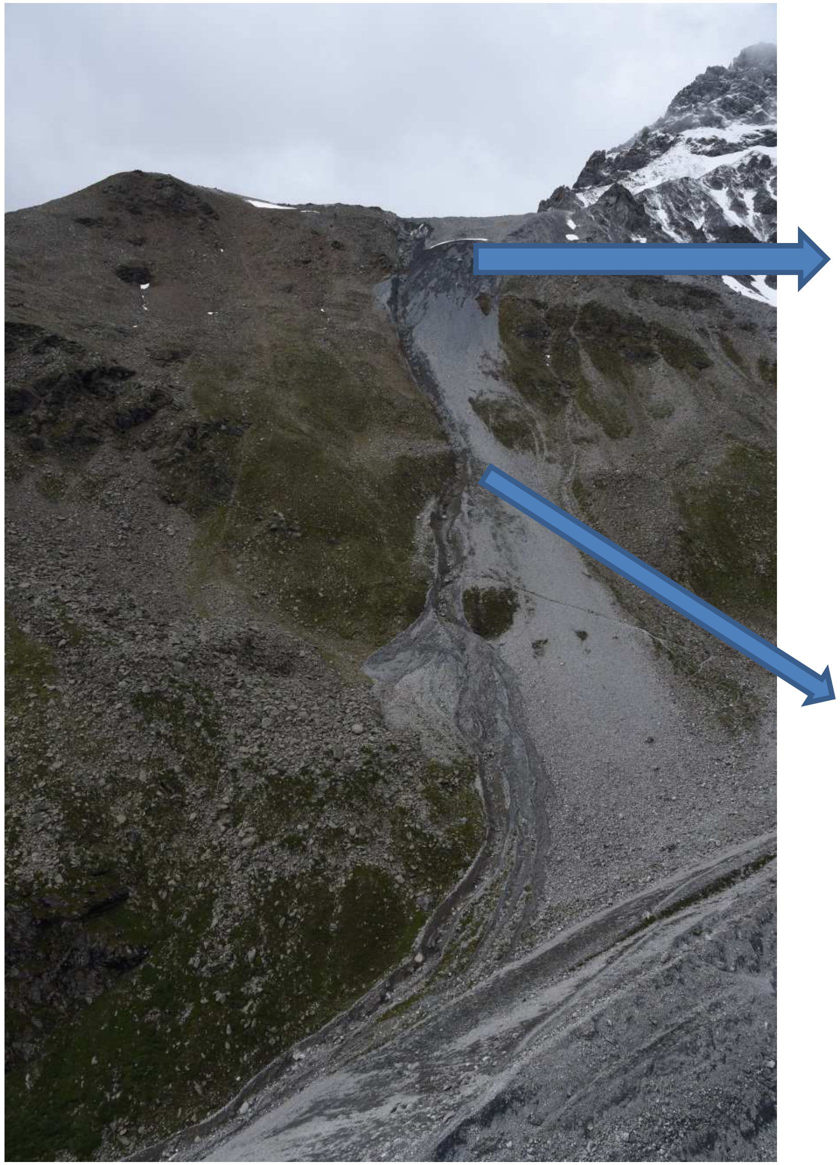
- GLOF



From Merkl et al (2015, EGU presentation)

Glacial and periglacial hazards

- Rapid mass movements



Rock glacier

Moraine

Photos courtesy of the Provincia di Bolzano