GLACIAL PROCESSES AND LANDFORMS

Glaciers affected landscapes directly, through the movement of ice & associated erosion and deposition, and indirectly through

- changes in sealevel (marine terraces, river gradients, climate)
- climatic changes associated with changes in atmospheric & oceanic circulation patterns
- resultant changes in vegetation, weathering, & erosion
- changes in river discharge and sediment load

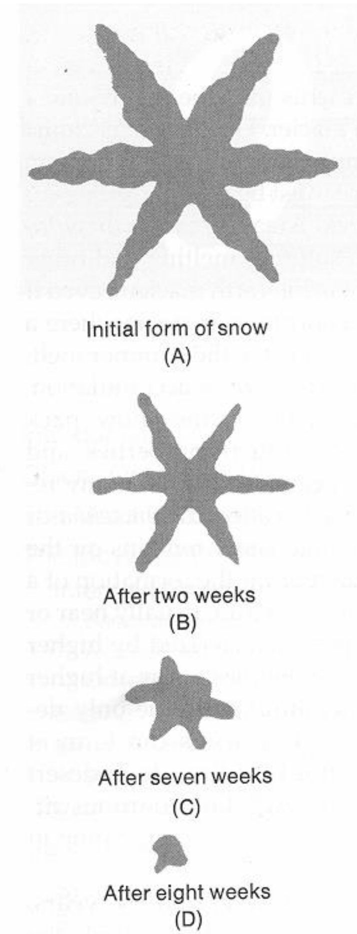
Many high-latitude regions are dominated by glacially-produced landforms

Glacial origin

Glacier: body of flowing ice formed on land by compaction & recrystallization of snow

Accreting snow changes to glacier ice as snowflake points preferentially melt & spherical grains pack together, decreasing porosity & increasing density ($0.05\ g/cm^3 \longrightarrow 0.55\ g/cm^3$): becomes firn after a year, but is still permeable to percolating water

Over the next 50 to several hundred years, firn recrystallizes to larger grains, eliminating pore space (to $0.8\ g/cm^3$), to become glacial ice



Mont Blanc, France


Mont Blanc
Google Earth
Image © 2018 DigitalGlobe
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10 km

Glacial mechanics

Creep: internal deformation of ice

creep is facilitated by continuous deformation; ice begins to deform as soon as it is subjected to stress, & this allows the ice to flow under its own weight

Sliding along base & sides is particularly important in temperate glaciers

two components of slide are

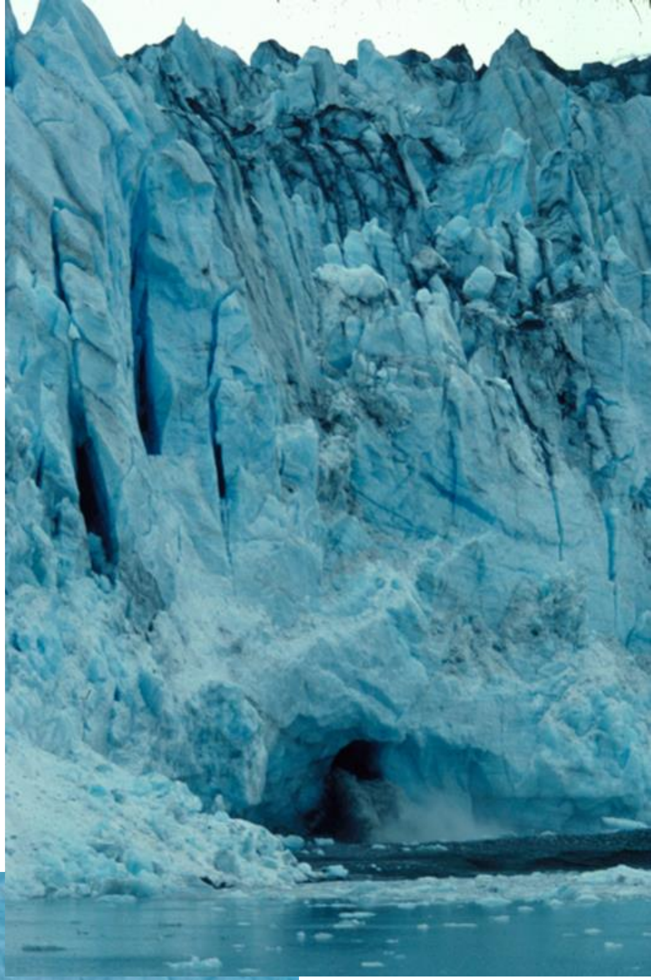
regelation slip – melting & refreezing of ice due to fluctuating pressure conditions

enhanced creep

Cavell Glacier, Jasper National Park, Canada

supraglacial
stream, Alaska

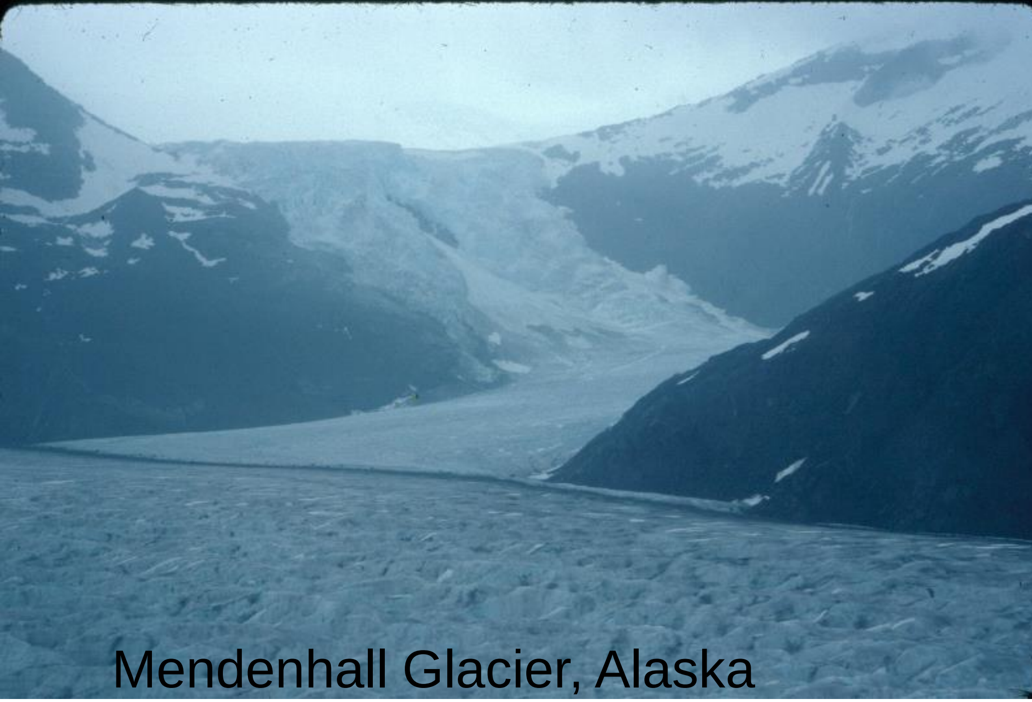
subglacial stream,
Alaska



Velocity along glacier

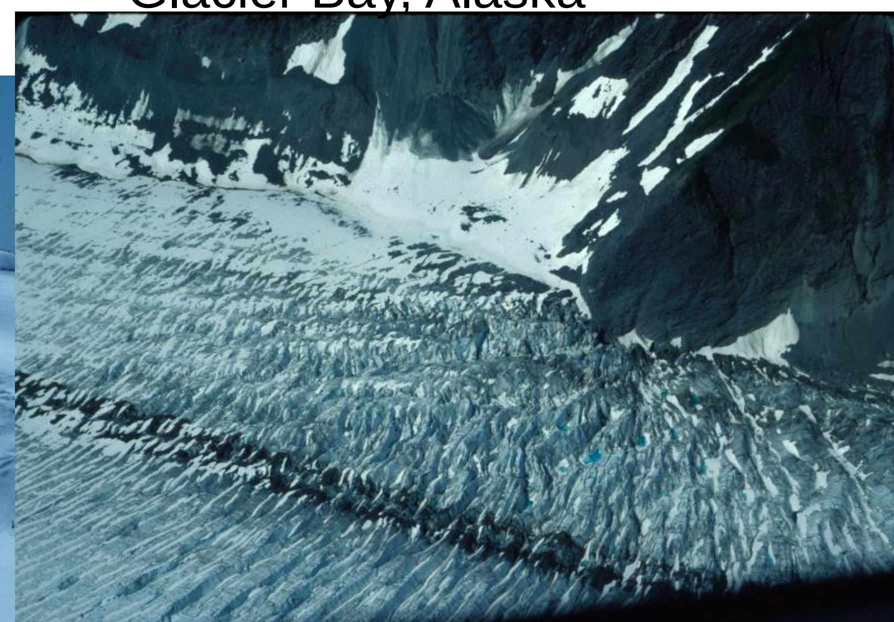
- increases to the equilibrium line as discharge increases ($Q = w\ d\ v$), & decreases after this line as ablation becomes active
- decreases from the surface to the bedrock & from the center to the edges as a result of boundary resistance and internal mechanics

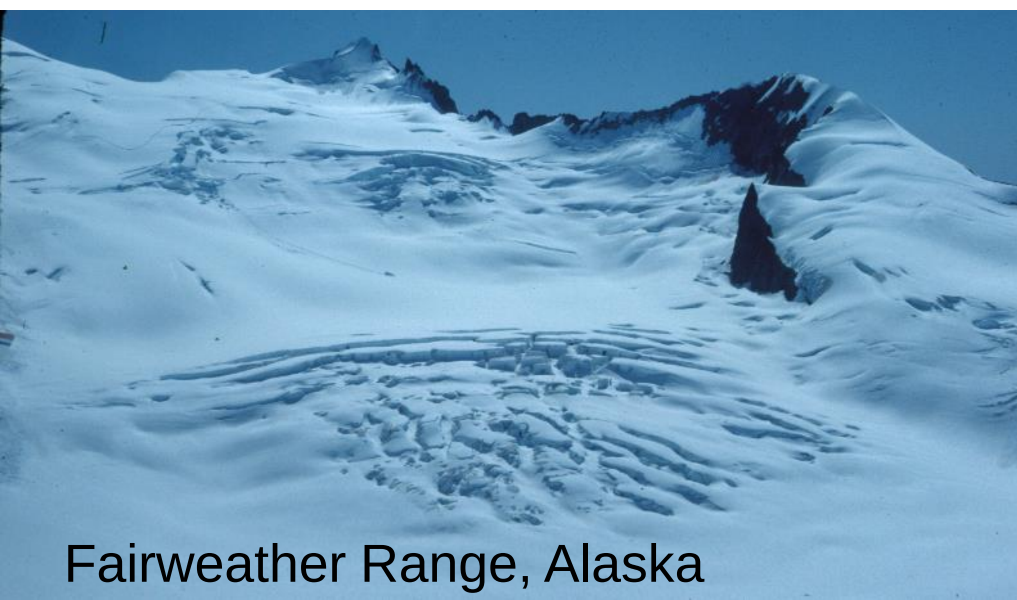
As ice flows, it thickens through compressive flow when the bed is concave upward or addition of ice is low, or thins through extending flow


Mendenhall Glacier, Alaska


Glacier Bay, Alaska

Glacier Bay, Alaska




Fairweather Range, Alaska

Glacier Bay, Alaska

Surging glacier: movement may have characteristics similar to kinematic wave, but does not require external stimuli such as mass addition

- sudden, brief, large-scale ice displacements periodically occur
- move 10-100 times faster than normal
- periodicity at 15-100 years
- probably due to unique conditions creating cyclic instability within the glacier
- fairly common phenomenon
- surge chaotically breaks surface
- key may lie in mechanics of basal sliding (eg. meltwater lowers basal shear stress)

Types of glaciers

Morphological: based on glacier size & environment of growth

- cirque glaciers
- valley glaciers
- piedmont glaciers
- ice sheets

Dynamic: based on observed activities of glaciers

- active – continuous movement of ice from accumulation zones to edges
- passive – not enough new snow, or low slopes; very low velocity
- dead – no internal transfer of ice from accumulation zone

Thermal: based on temperature of ice

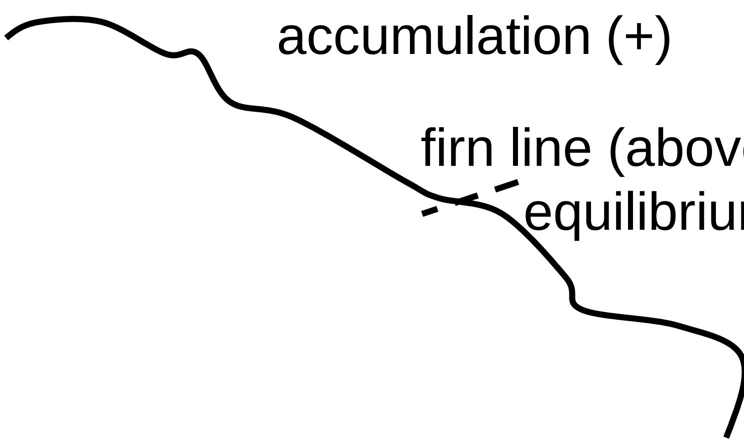
- temperate – ice throughout mass is at pressure-melting point, abundant meltwater; high velocity & erosive action
- polar or cold – absence of meltwater means ice at base is frozen to underlying rock – slippage can’t occur (movement is internal) – erosive action much less

Generally, valley glaciers are active, & temperate ice sheets are polar and passive

Glacial budget: mass balance of glacier; budgeting of gains & losses of mass on glacier during specific time interval

accumulation	ablation	
snow	melting	sublimation
rain & other water	evaporation	calving
avalanches	wind erosion	

Usually consider one budget year (time between two successive stages) when ablation attains maximum yearly value – usually end of summer



+ mass balance: advance; steep or vertical front

-- mass balance: recede; gently sloping, partially buried snout

rates of accumulation & ablation matter, as well as overall balance

temperate glaciers – high accumulation & ablation rates, move rapidly

polar glaciers – low accumulation & ablation rates, passive

} both may have 0 net balance

Ice structures

Primary

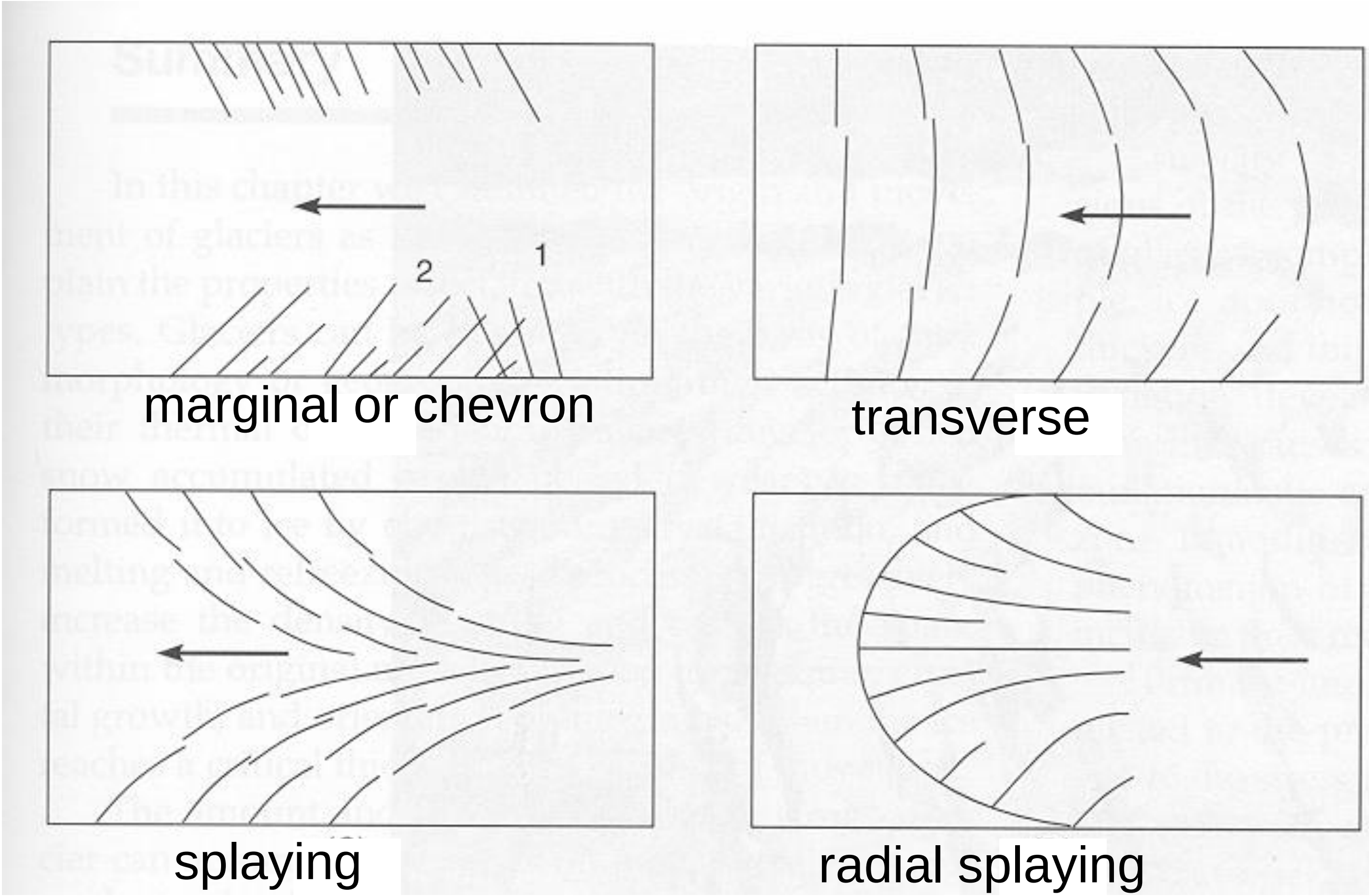
stratification: layers or bands within ice due to annual cycle of snow accumulation & ablation – debris & textural differences separate bands

Secondary

foliation: layering produced by shear during ice motion, produces alternating clear blue & white bubble-rich ice

crevasses: cracks in ice surface; reflect tensional stress, usually perpendicular to direction of maximum elongation, although also

- splay or radial crevasses near centerline where spreading exerts component of lateral extension
- chevron/en echelon crevasses near ice margins where shear stress parallels valley walls and crevasses form diagonal to valley sides
- transverse crevasses where ice extends in longitudinal direction (eg ice falls)


2
1
marginal or chevron
transverse
splaying
radial splaying


Google Earth
Image © 2018 DigitalGlobe
800 m
N

ogives: at base of ice fall crevasses are closed by compression & band of dirt-stained ice forms in summer – in winter the ice descending the fall reconstitutes into clear, bubbly ice; the annual down-valley flow produces a series of alternating white & dark bands called ogives

Taku Valley, Alaska

Erosional Processes and Features

Glacial erosion occurs via

abrasion: scraping from debris carried in ice, depends on relative hardness of debris & bedrock; amount of debris; and velocity of flow; about 0.06-5 mm/yr

quarrying/plucking: ice exerts shear force on rock loosened by fractures & meltwater freezes to rock as glacier thickness/ velocity/meltwater fluctuate

Abrasion features

striations: mm deep, continuous only for short distances

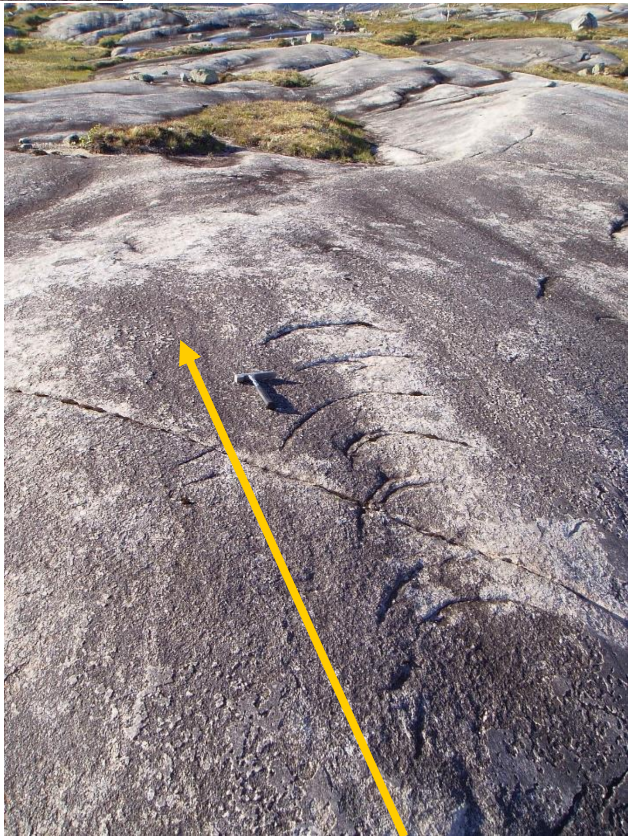
grooves: 1-2 m deep, 50-100 m long, boulders carried along

crescentic marks: chipping of underlying rock

striations, Athabaska Glacier, Canada

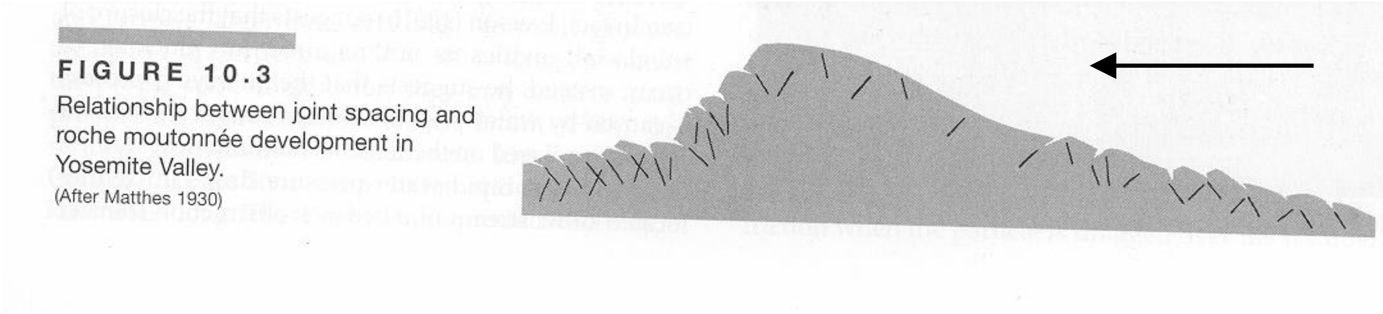
glacial polish, Yosemite, CA

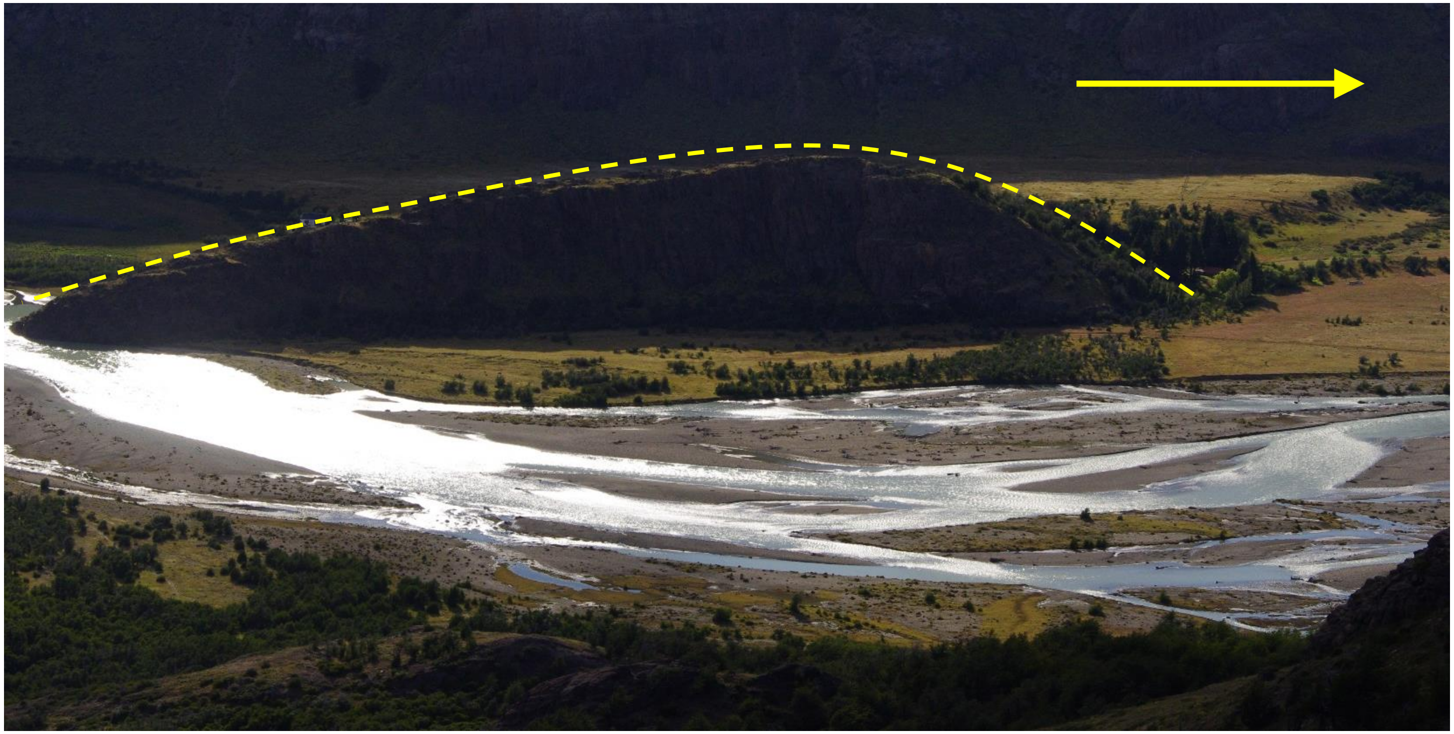
crescentic gouges,
northern Norway



Plucking features

roche moutonnee: abrasion upstream & plucking downstream, promoted by irregular spacing of bedrock fractures

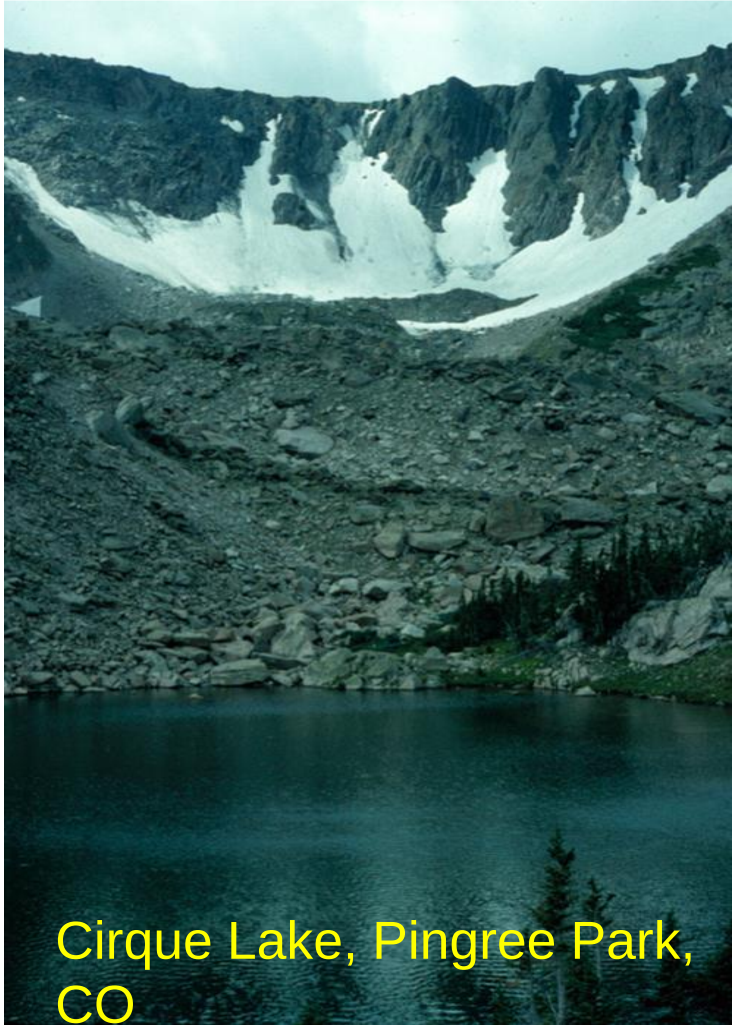




Patagonia, Argentina

Other features

cirque: deep, erosional recess with steep & shattered walls at the head of a mountain valley, semicircular in plan view like ampitheater; bowl may contain lake called tarn dammed by rock lip with moraines



Cirque Lake, Pingree Park, CO

cirque & tarn, Glacier National Park, MT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5 km
Google Earth

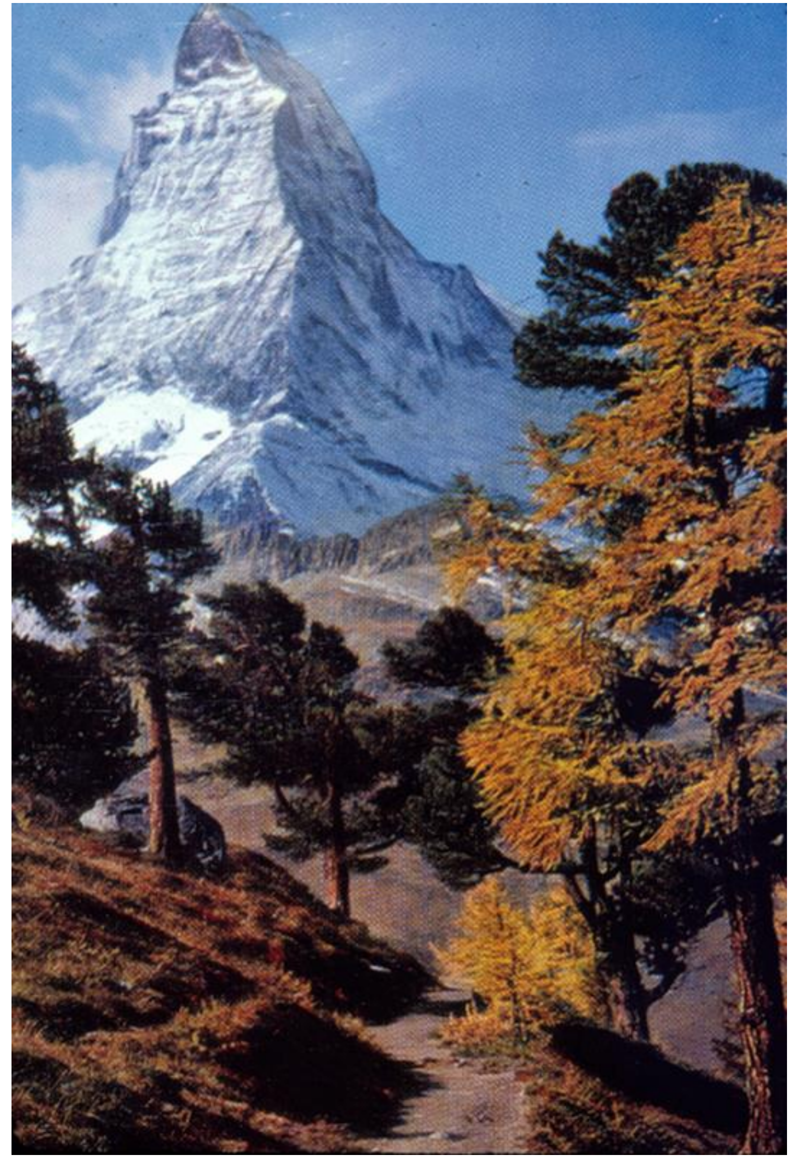
Size & shape of cirque are a function of
- rock type (larger & more well-developed in igneous or highly metamorphosed rocks)
- rock structure
- preglacial relief
- time span of glaciation

Elevation is controlled by snowline elevation at time of formation, orientation with respect to solar radiation & prevailing winds

Cirques grow headward & laterally to form horns and arretes

Matterhorn, Switzerland

horn, Glacier National Park, MT



Machapuchre, Nepal (horn)


Matterhorn Glacier
Google Earth
Image © 2018 DigitalGlobe
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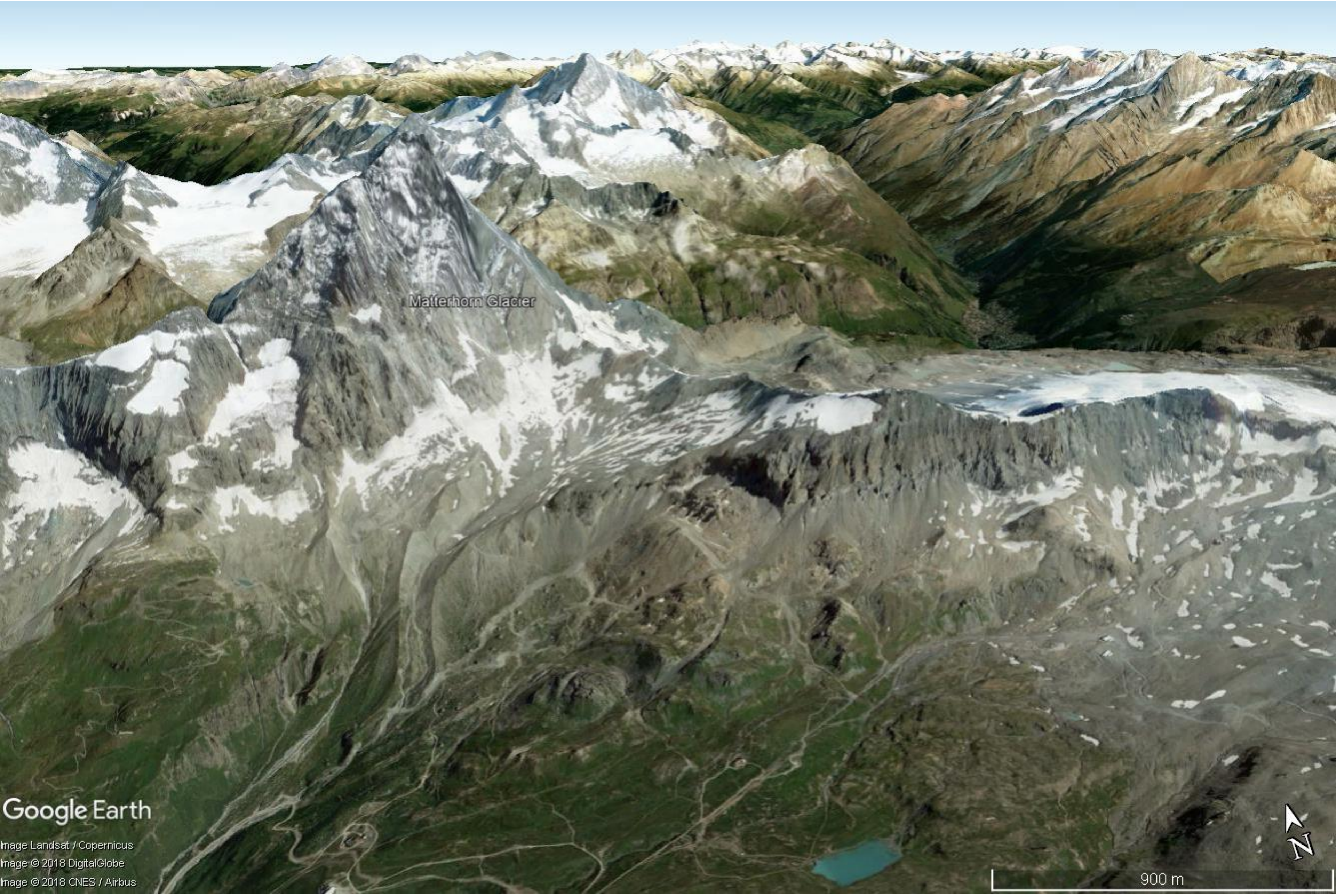
3 km


Matterhorn Glacier
Google Earth
Image Landsat / Copernicus
Image © 2018 DigitalGlobe
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900 m
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Cirques develop through

mechanical weathering & mass wasting: accumulating snow & firn percolate into rock fractures – pressure fluctuates during freeze & thaw, and particles move downslope by creep – nivation

erosion by cirque glaciers: move by rotational sliding as ice slides and rotates

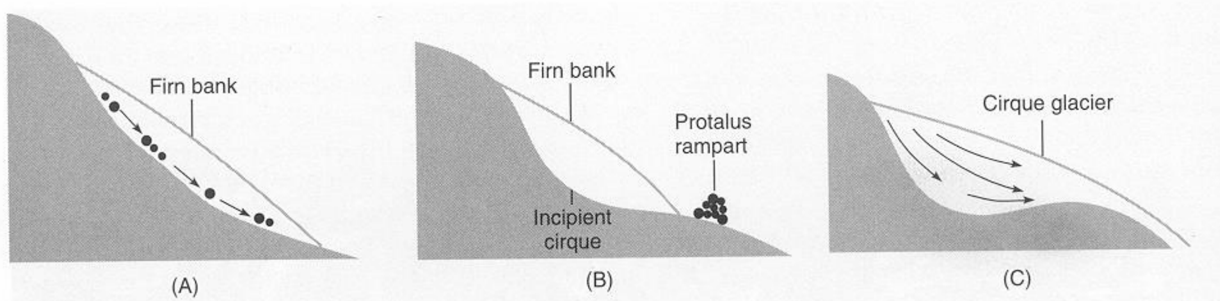


FIGURE 10.7
Stages of cirque development. (A) Nivation beneath firn bank. (B) Nivation cirque. (C) Cirque with fully developed cirque glacier.

rounded, glaciated topography, Acadia National Park, Maine

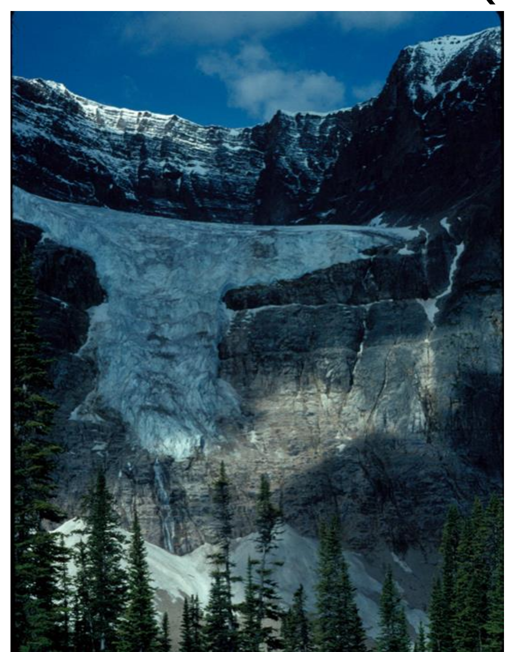
glaciated landscape, Kings Canyon National Park, CA

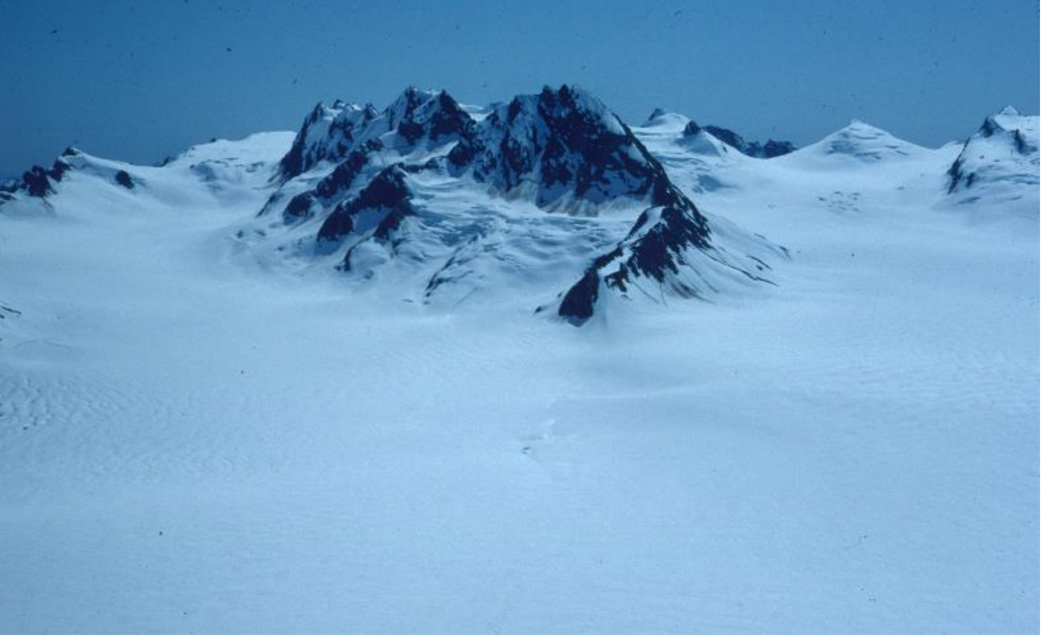
Nunataks: residual peaks of rock above ice when cirque glaciers merge to form ice cap

Glacial trough: steep, near-vertical sides & wide, flat bottoms; u-shaped valley created from v-shaped river valley through lateral and vertical erosion; tend to have irregular longitudinal profiles of basins with paternoster lakes & steps; also hanging valleys where tributary glaciers with less ice join the main valley

Fjords: glacial trough partially submerged by ocean; development occurred when ice was physically beneath ocean (too deep for sealevel drop)

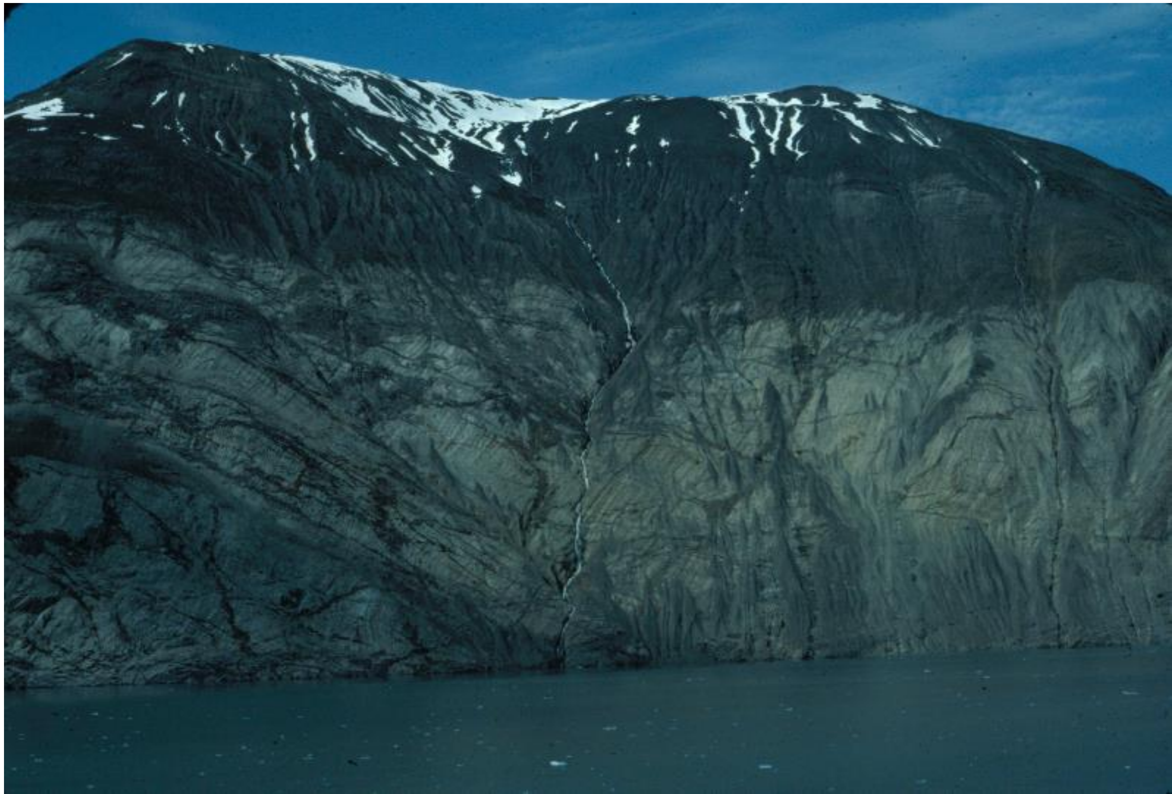
hanging valley glacier, Jasper National Park, Canada





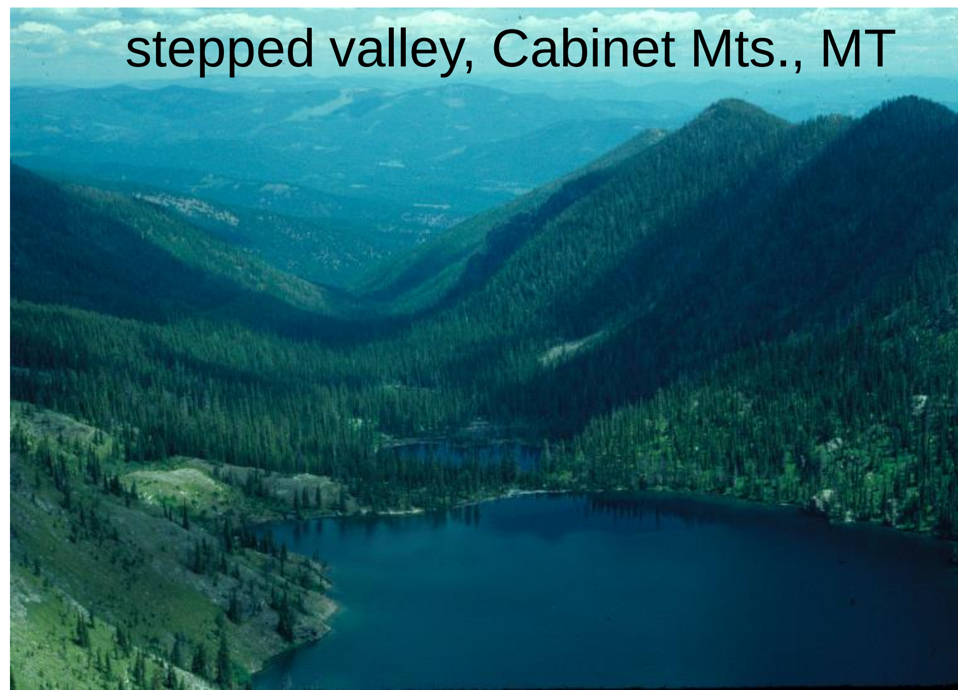
nunatak, Fairweather Range, Alaska

glacial trim line, Glacier Bay, Alaska



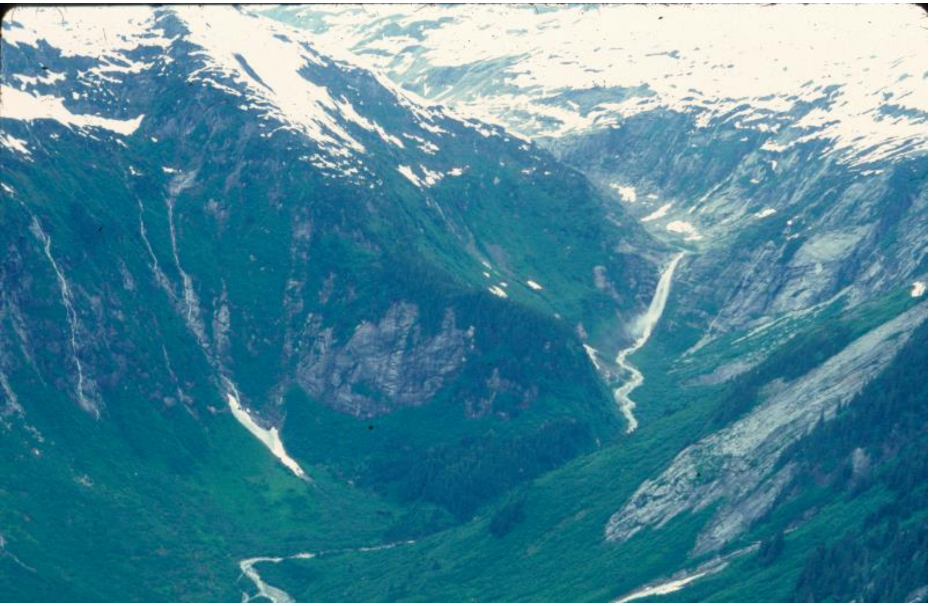
u-shaped valley, Glacier N.P., MT

glacial tarn, Bighorn Mts., WY

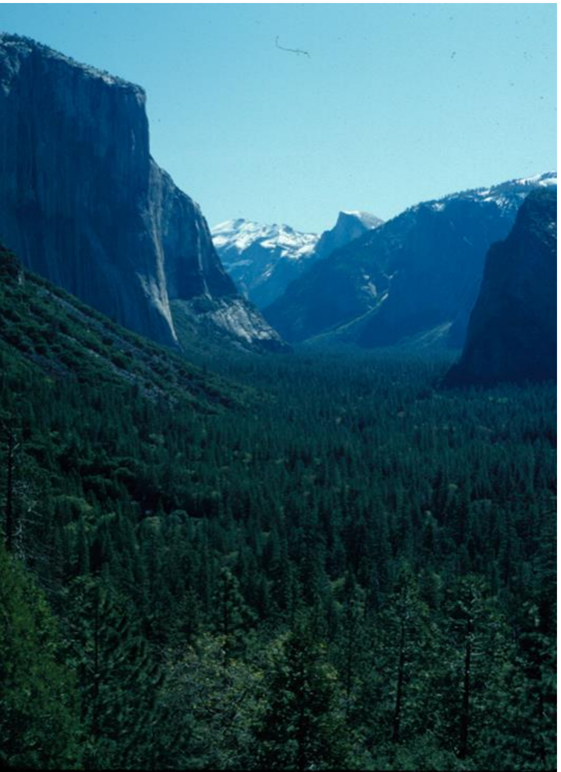


stepped valley, Cabinet Mts., MT

upper Taku Valley, Alaska



lower Taku Valley, Alaska



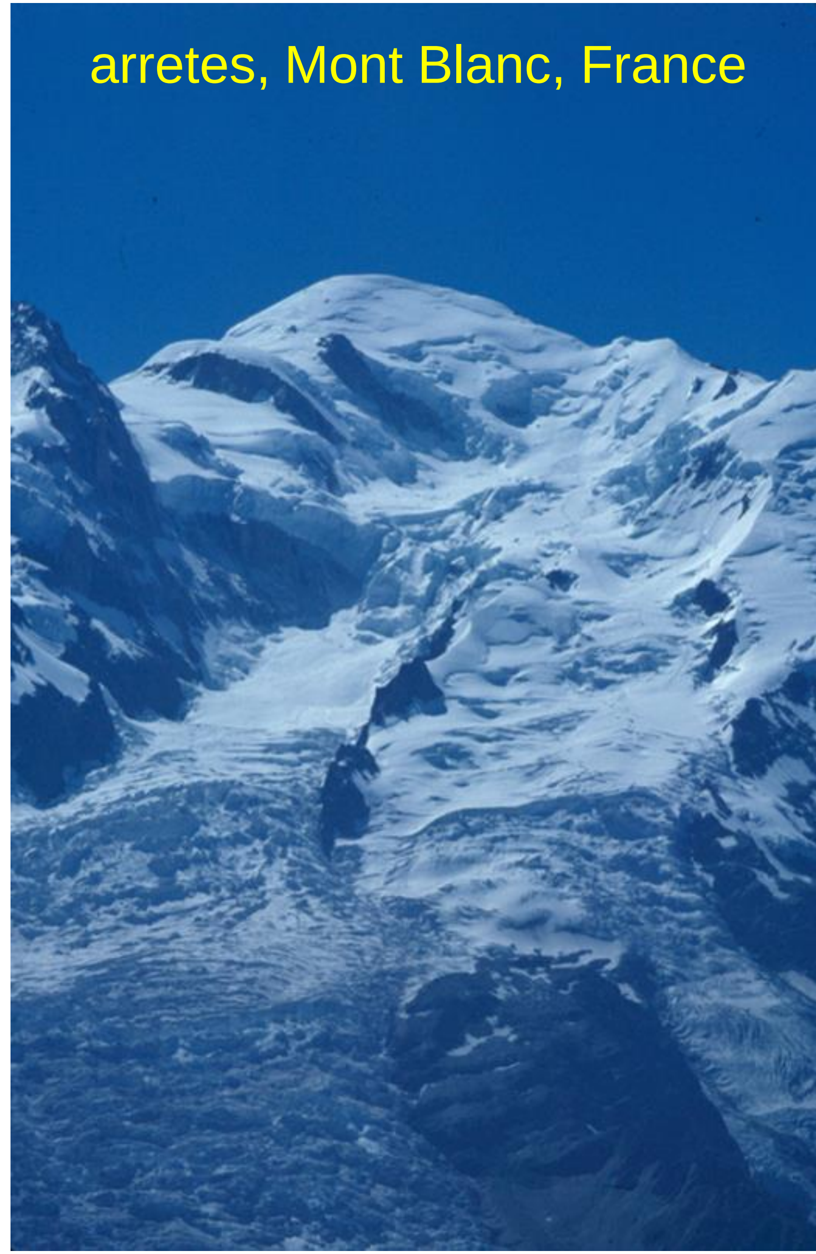
Yosemite Valley, CA

fjord, Norway

u-shaped valley, Norway

Thunersee, Switzerland


arretes, Southern Patagonia Icefield


arretes, Mont Blanc, France


Prince William Sound, Alaska