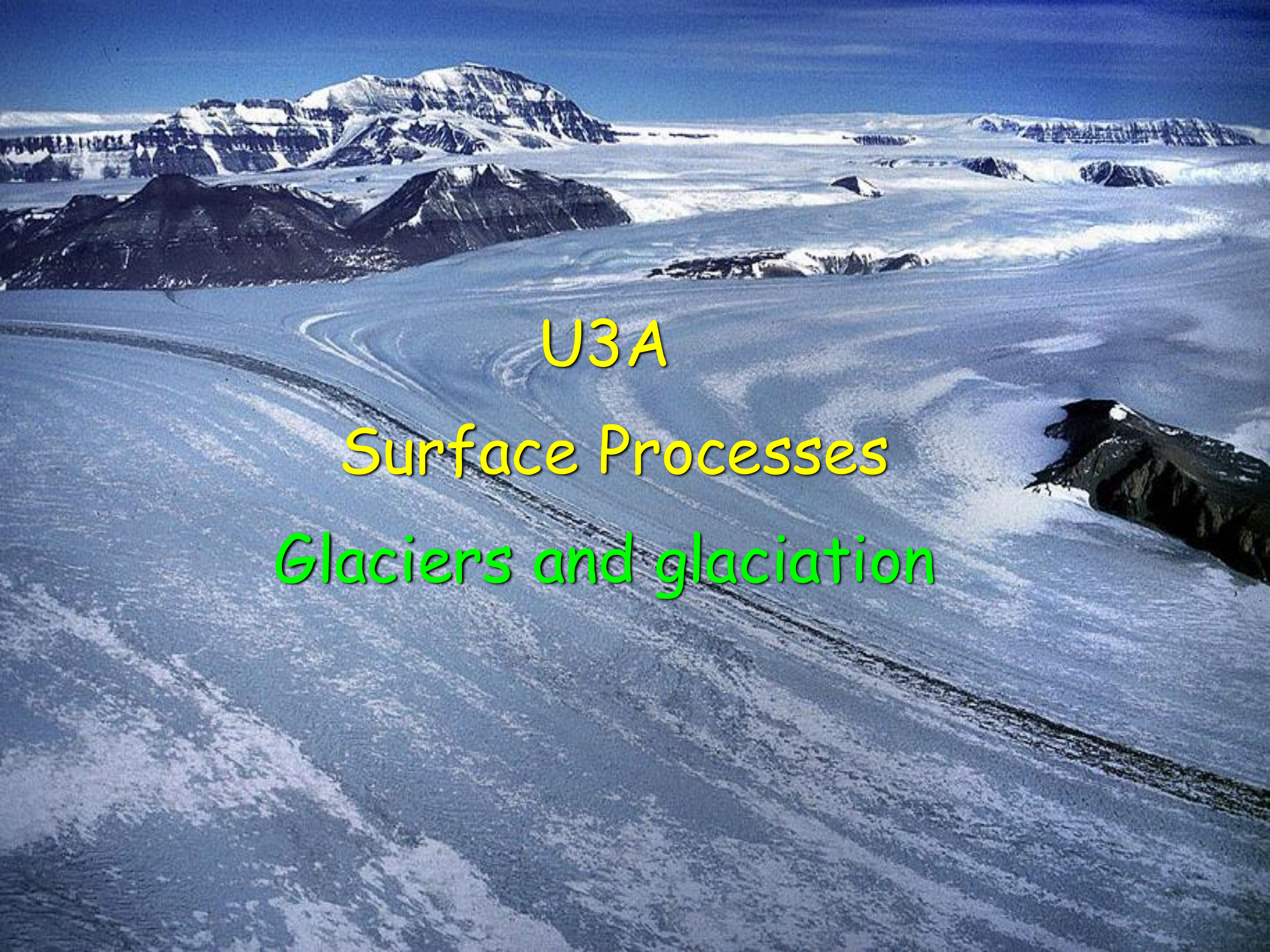

U3A
Surface Processes
Glaciers and glaciation

Glaciers

- Systems of flowing ice → move from high altitude → lower altitude
- accumulation of ice formed from compaction of snow
- about 10% of continental surface covered by ice, mostly glacial
- during coldest part of last glaciation ~16,000yrs ago ~30% of Earth was covered by glaciers
- glaciers → flow plastically under pressure

Satellite photograph – Bear Glacier, Alaska

Vatnajökull icecap, Iceland

Europe's largest (area = 8,100 km^2)

(av. thickness 400m ; max 1100m)

Formation of glaciers

- Originate in permanent snow fields (above snowline)

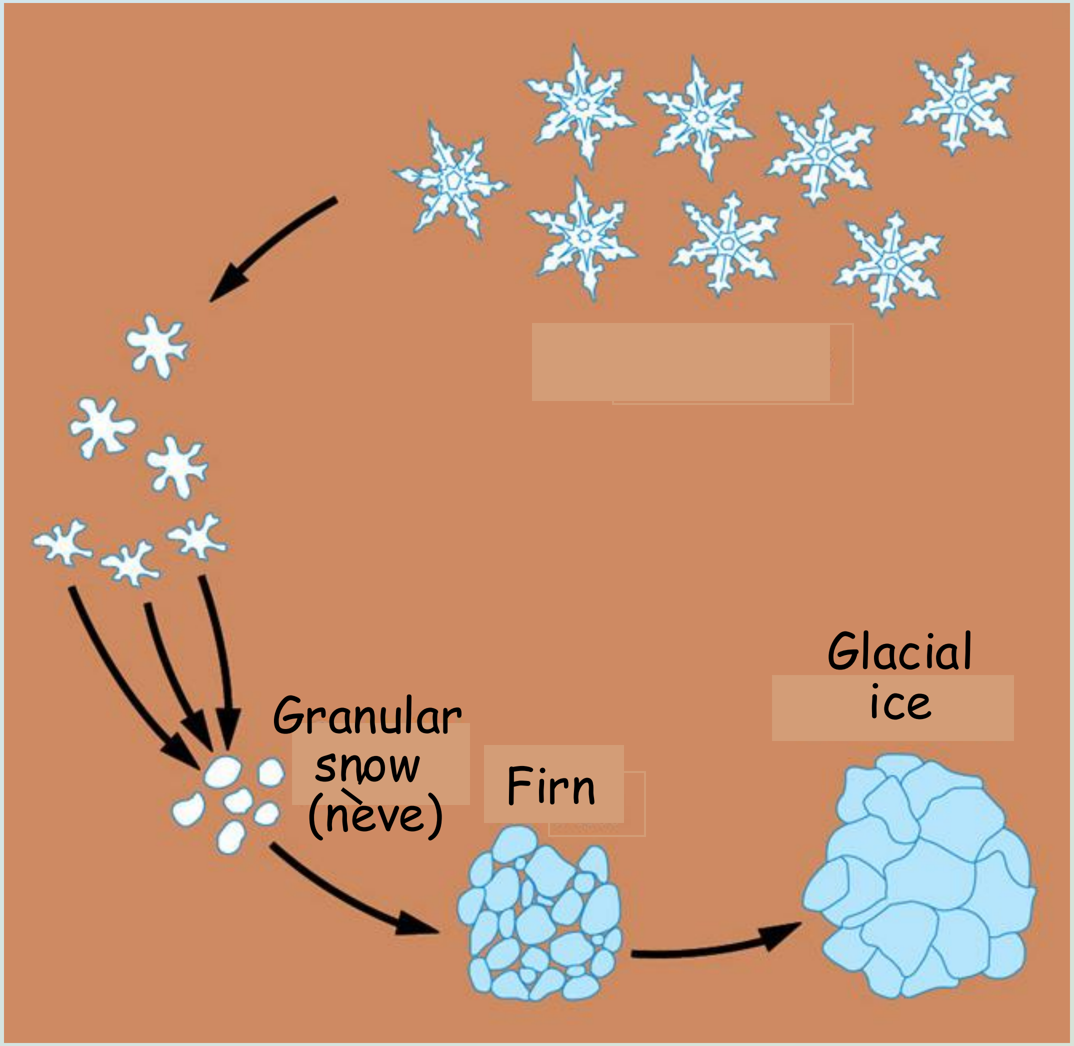
  - vary from sea level (Antarctic, Arctic) to 4,400m in equatorial Africa also in the Andes and Irian Jaya

  - none in Australia → no permanent snowline nor enough accumulated snow

- Begin with compaction of fallen snow

  → fresh snow is porous with low density → compaction, melting and evaporation → small rounded granules (neve) → compaction → firn → ice → moves downslope under gravity as glacier

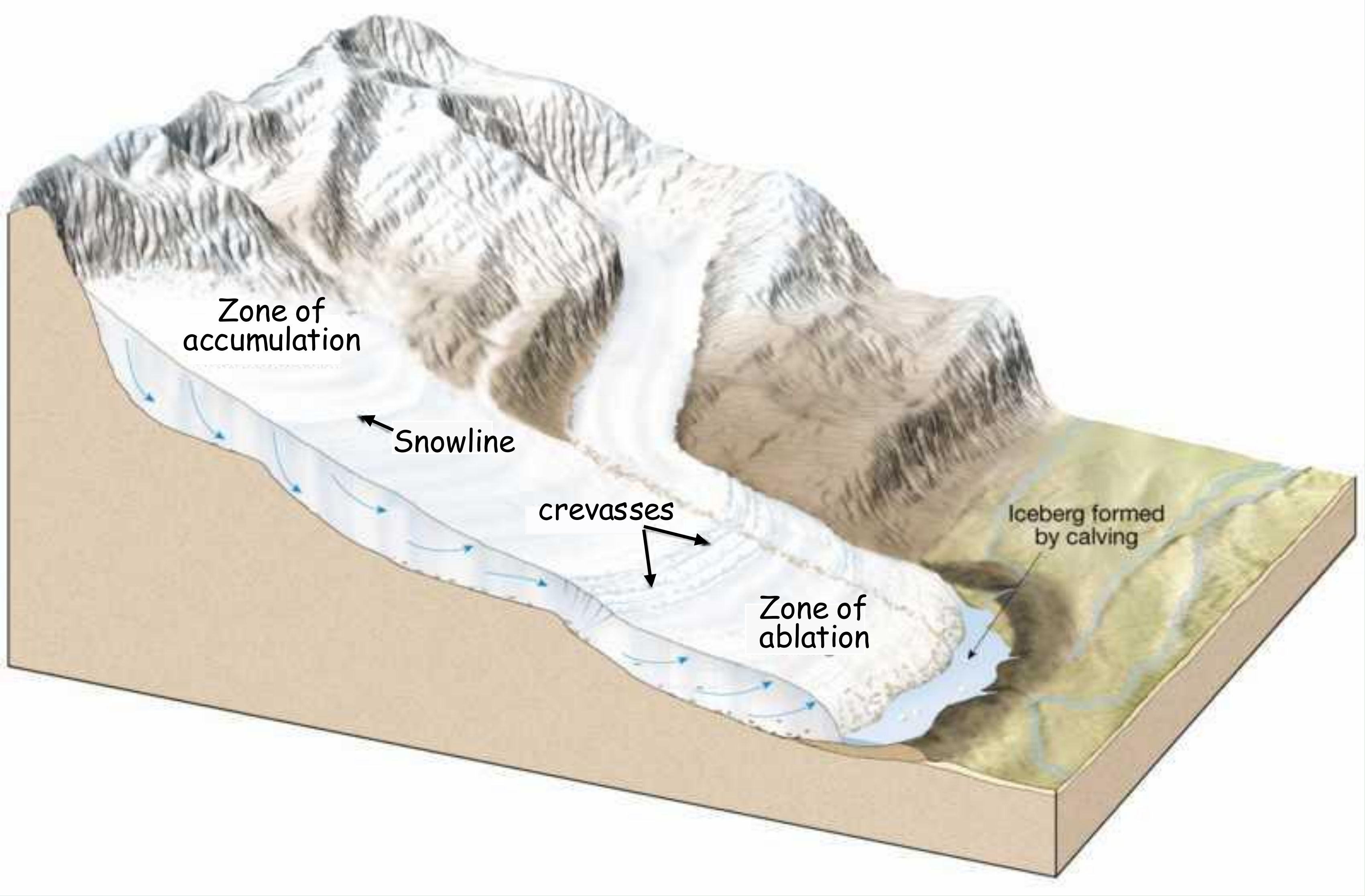
Formation of glacial ice



Snow ⇒ Granular snow ⇒ Firn ⇒ Glacial ice

10% water   50% water   70-80% water   >80% water

Glacial zones



Movement of glaciers

- Different parts of glaciers move at different rates
- glaciers are faster moving in the centre of the glacier
- upper part of glacier (up to 70m thick) rigid, brittle → crevasses
- typical glacial movement 1m/day, (fastest moving ~45m/day)
- movement occurs in combination of two ways:

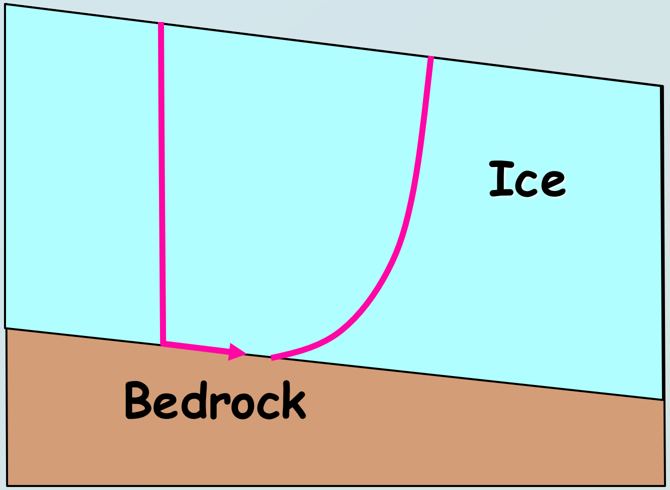
(1) internally by slow, laminar, plastic flow → about 10m/yr

(2) by slip at base of glacier

  - temperate glaciers, melting at base → water → 1400m/yr
  - polar ice frozen to bedrock → slow creep → few m/yr

Slip and flow

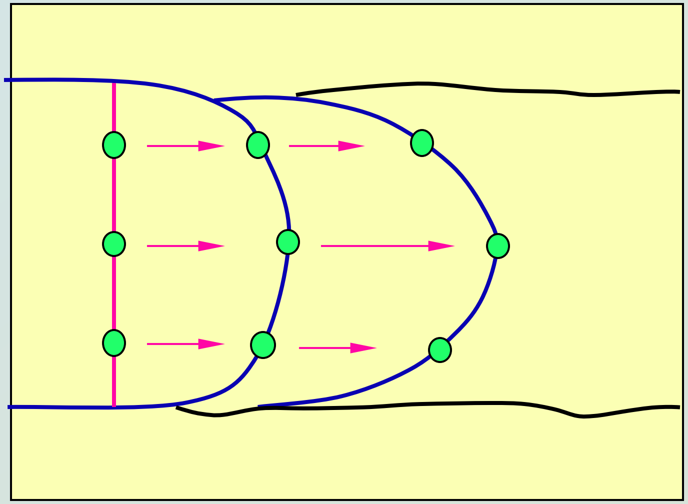
Originally vertical pipe bends and moves downslope



Cross-section

Movement is a combination of basal slip and internal flow

Markers on ice move fastest in centre - plastic flow



Plan view

Types of glaciers

- Two types: (1) Valley (alpine) glaciers - flow along valley channels
  (2) Ice caps and ice sheets - flow radially outwards
  from the centre of a dome
- flow determined by topography over which they flow

Athabasca glacier,
Canadian Rockies

Alpine glaciers

- Form in high mountain ranges (e.g. Europe, NZ, Americas)
  - form when rate of accumulation of snow exceeds rate of melting
  - form valley glaciers
  - extend below snowline
- typically ~300metres maximum thickness
- carve out glacial valley

Franz Josef glacier,
South Island, NZ

Piedmont glaciers

- Produced when two or more valley glaciers coalesce to form a broad piedmont glacier
  - runs out from mountain onto plain

Yentna Glacier, Alaska

Ice caps and ice sheets

- Ice caps
  - large sheets of ice on land (e.g. Iceland) unrelated to oceans
- Continental ice sheets
  - very extensive, up to thousands of km wide (Antarctica)
  - domed features with shallow slopes
  - usually shallowly dipping curved features
  - may exceed 3km in thickness (but not by much)
  - extend to coast, feed valley glaciers, ice shelves

  e.g. Antarctica, Greenland

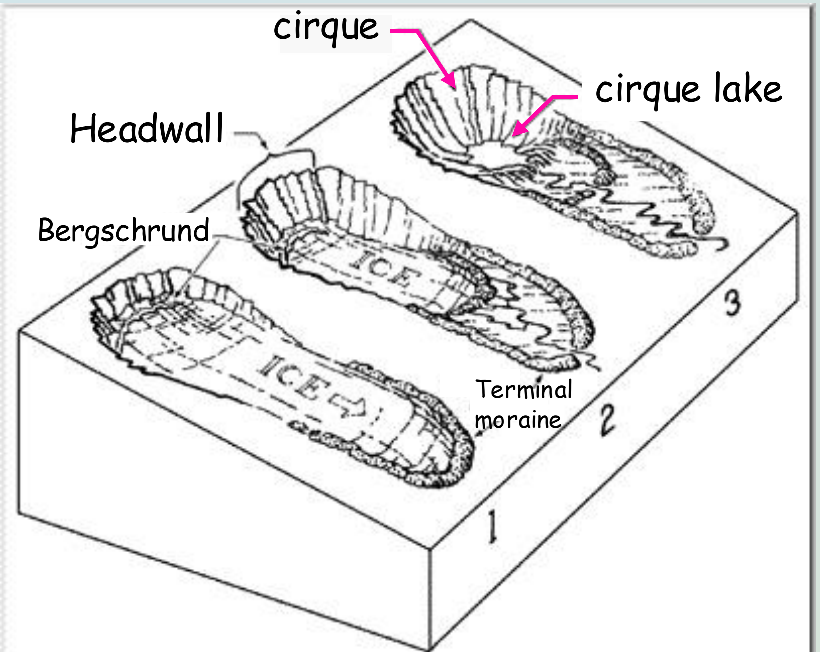
Ice sheet - Antarctica

- Vast sheet of ice → covers a continent larger than Australia
- moves outwards from a number of large domes
- many glaciers feed ice shelves → floating extension of ice sheet
- increase in gradient of bedrock → tension fractures (crevasses)

Antarctic ice sheet

Cirques

- Cirques
  - carved out at head of glacier → unique landform
  - steep on three sides open downslope (bowl-like depressions)
- starts as snow hollow
  - deepened and enlarged by frost wedging and plucking
  - wedging undercuts walls → depression with steep walls



Development of cirque at head of alpine glacier


Cirque, Alaska

Cirque growth

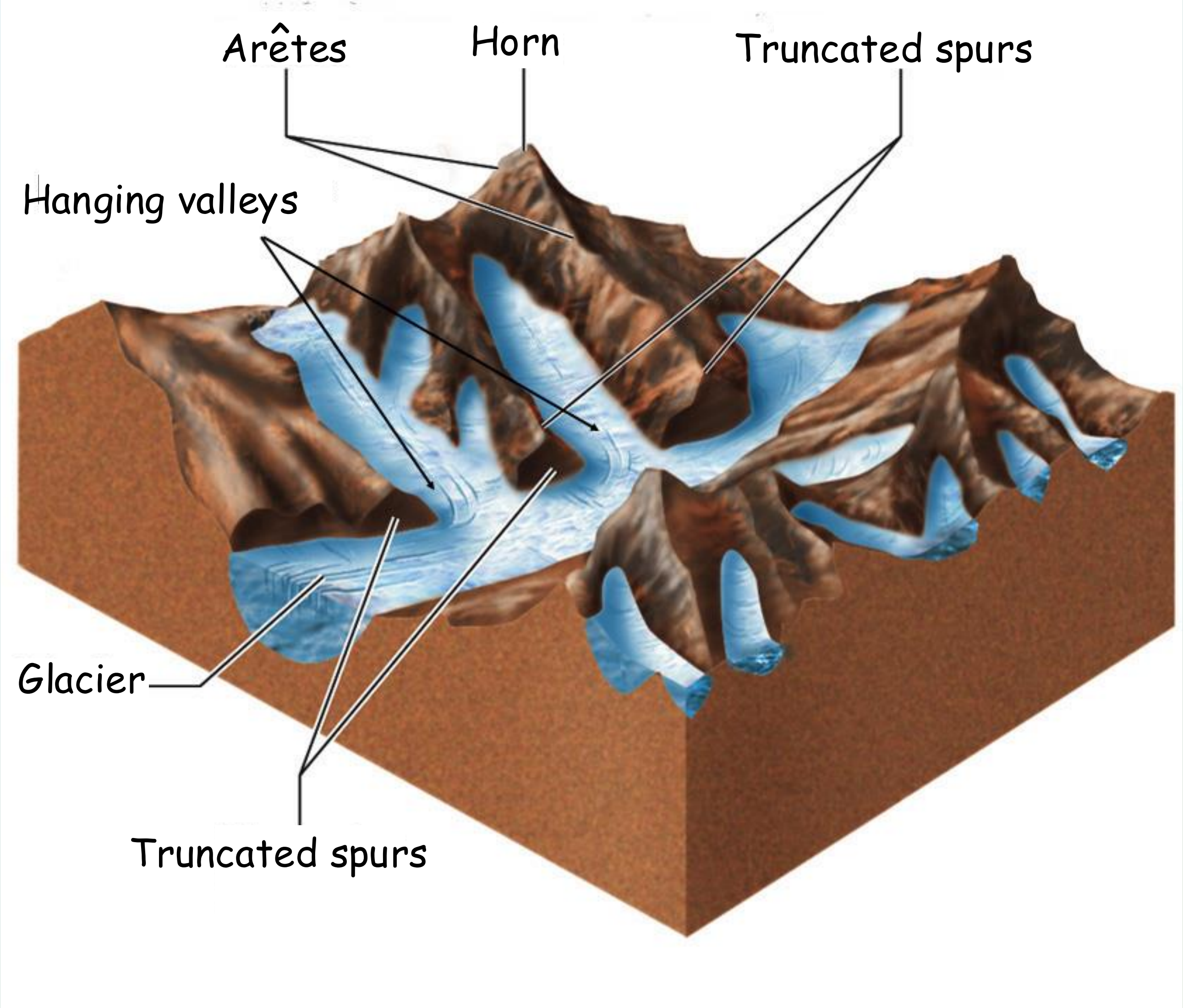
Cirques can converge with one another to form horns and arêtes

- sideways growth of adjacent cirques→ razor ridges (arêtes), pyramid peaks (horns)

Arête

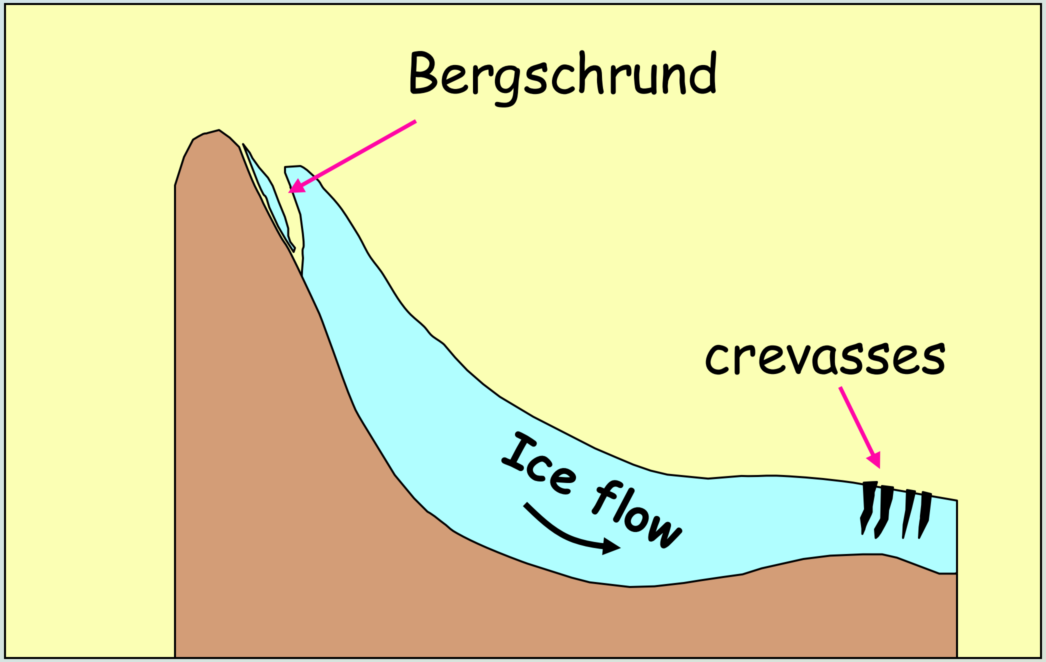
The Matterhorn, Switzerland

Other glacial landforms



Fractures in glacier

- Glacier in cirque develops fractures (crevasses)
  - Bergschrund → crevasse against cirque wall
  - crevasses → where glacier flows over front rim of cirque



Cirque cross-section

Bergschrund

Bergschrund, Austrian Alps

Glacial erosion - products

- Base of glacier can freeze to bedrock and incorporates pieces of rock plucked from bedrock
  - like gigantic pieces of sandpaper
- rocks plucked from glacier floor → abrade, carve off other rock fragments
- underlying bedrock grooved and polished → striated pavement
- abrasion produces finely ground material
  - "rock flour" → turns meltwater streams milky
- glacial features are preserved in Australia

Striated pavement

- Grooves gouged by rock material embedded in base of glacier
- striations allow determination of direction of movement

Glacial striations

Ontario, Canada

Striated pavement, Lake Epalock, Vic

Roche moutonnée

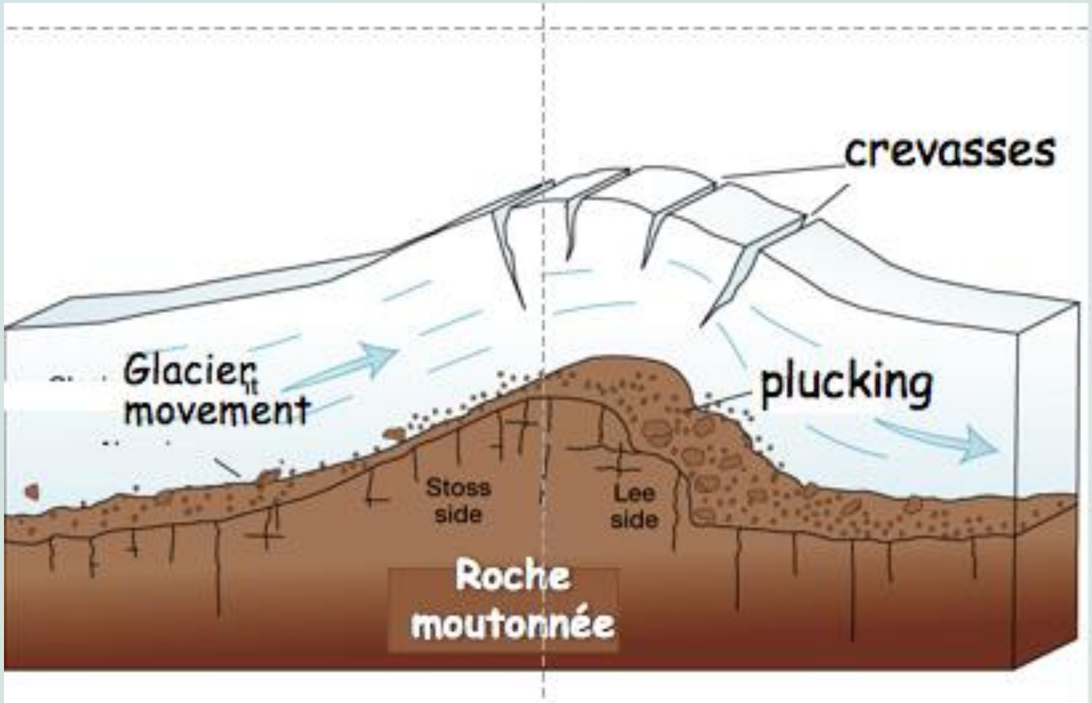
- Glacier erodes bedrock → small stream-line hills in bedrock

  - small bedrock knobs, abraded to smooth surface on upflow side

  - plucked on downflow side due to water freezing

    in joints, gives rough surface

- called roche moutonnée (sheep rock)



Roche moutonnée, Bernese Alps, Switzerland

Glacial valleys

- Filled with glacial ice to high level
- erosion on sides as well as base → U-shaped valleys
  - contrast with V-shaped valleys of rivers
- truncated spurs
  - contrast with interlocking spurs of river valleys → glacier will erode straight through spurs

Leh valley, Indian Himalaya

Hanging valleys

- Glaciers may have a number of tributaries (similar to streams)
- minor tributaries feed more fast flowing trunk glaciers
- erosion in side valleys less than in main valley

  → floors of side valleys deepened at slower rate
- retreat of ice leaves them as hanging valleys

Hanging valley

Milford Sound, NZ

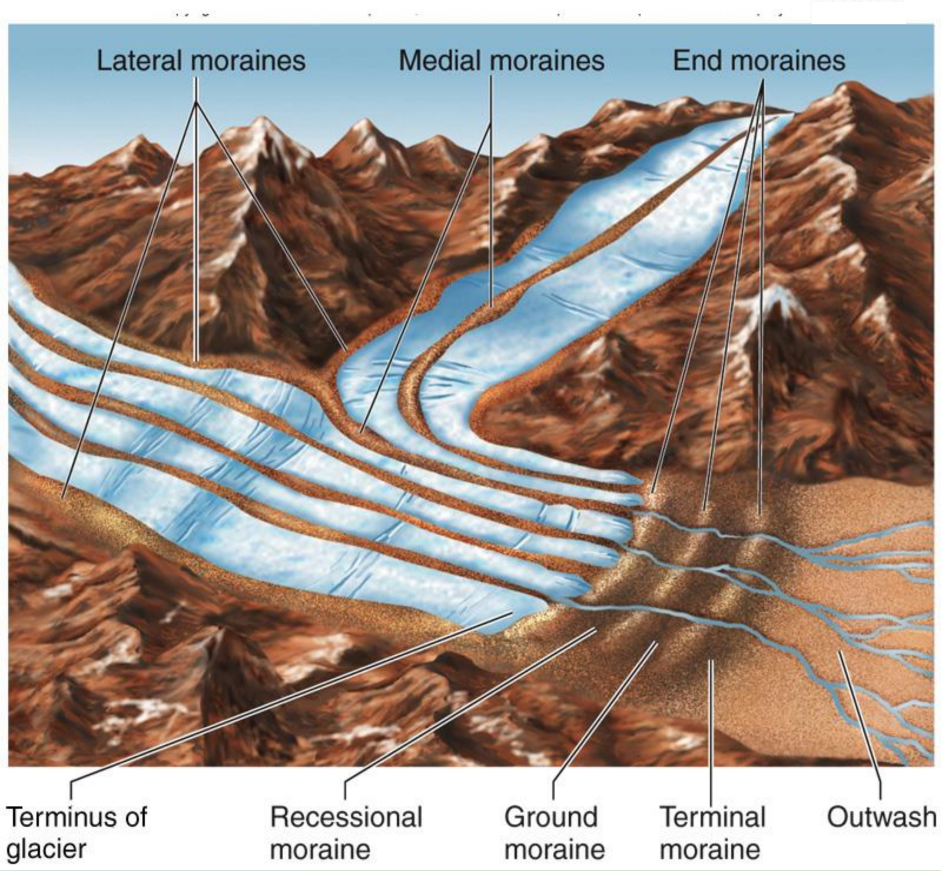
Fjords

- Fjords → partially submerged glacial valleys (Norway, Greenland, NZ)
- sea level lower during ice ages → water locked up as ice
  - glaciers able to erode to lower elevation
- glaciers retreat → sea level rises
  - drowns glacial valleys
  - forms fjords
- fjords
  - characterised by steep walls
  - often form deep water inlets

Fjordland,
South Island, NZ

Glacial deposits - moraines

- Glaciers very effective in eroding → produce large volume of different materials as they cut through countryside
- glaciers occur where weathering is very active
- glacial deposition: material transported by glacier → moraine



Ground moraine

- Derived from material plucked from underlying bedrock
- may be washed out of glacier by melt water or left behind by retreating glacier

Poorly sorted debris deposited from melting ice as glacier retreated, Skaftafell, Iceland

Lateral moraine

- Lateral moraines form ridges along the edges of glaciers
- moraine derived from material broken from steep glacier valley walls
- ice wedging plays an important role in breaking up wall rocks

Deposit of lateral moraine in Austria, left behind by a retreating glacier

Medial Moraine

- Medial moraine
  - formed from lateral moraines when two glaciers merge

    form centre line of new glacier

Medial moraines

Edward Bailey glacier, Greenland

Terminal moraine

- Terminal moraine

  - form where rock material is dumped by melting snout of glacier

  - often forms high banks

  - may dam valleys

  - may eventually be washed away by streams

Terminal moraine

Pasu glacier, Pakistan

Till

Till → material deposited by glaciers

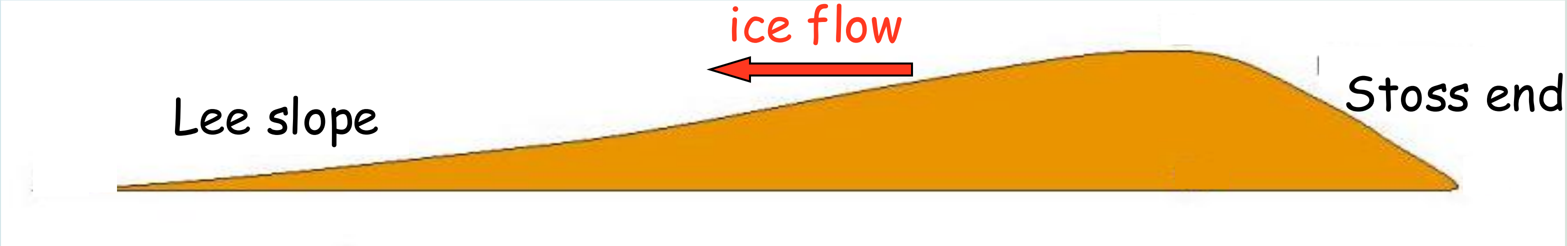
- very poorly sorted glacial deposits (different to river sediments)
- rock flour, sand, large angular pebbles → boulder clay
- when lithified forms a rock called tillite

Glacial till

Lake Ontario, Canada

Drumlins

- small elongate ridges of till left behind after glacier retreat
- formed by glaciers flowing over soft sediment
- up to 1km long, 500m wide, 50m high. Aligned in flow direction



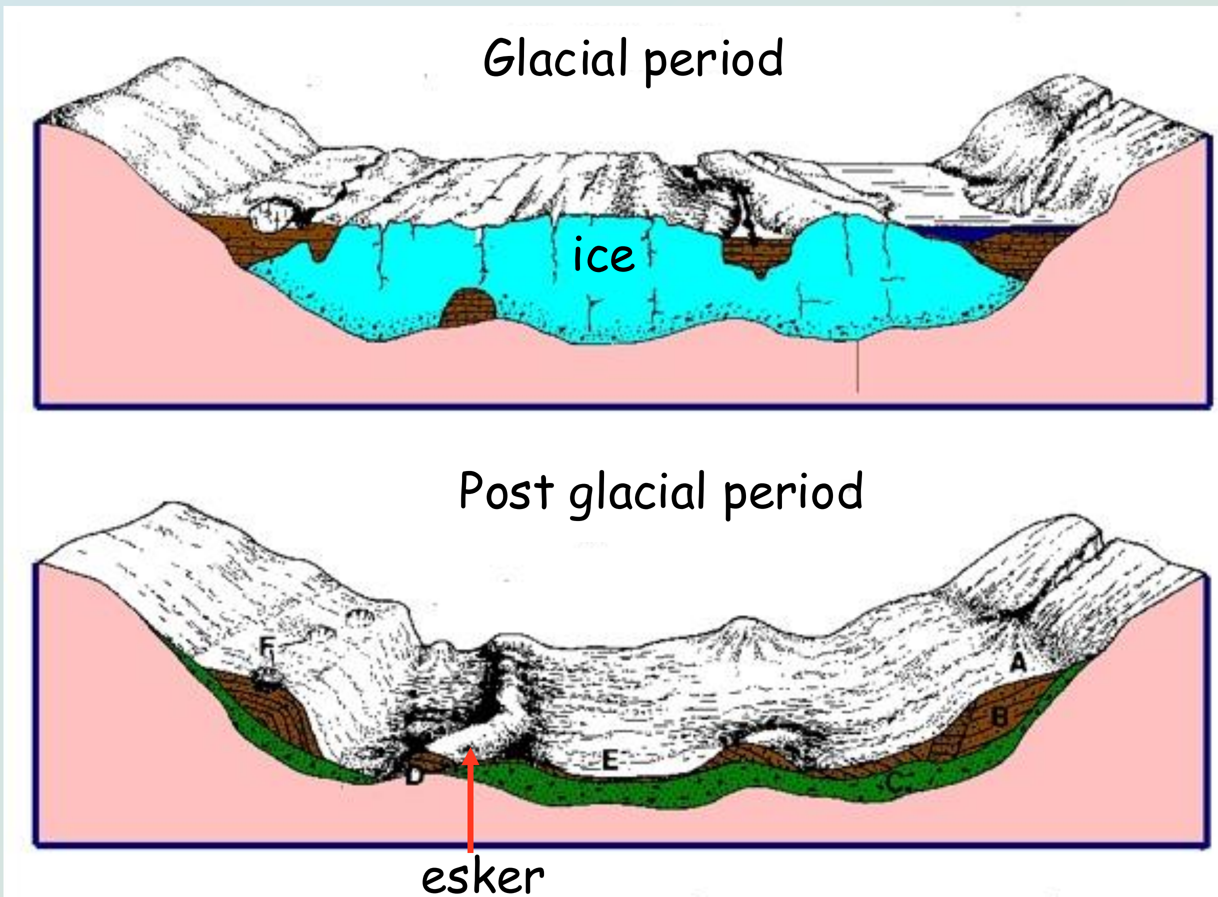
Drumlin, Yorkshire, UK

Fluvioglacial deposits

- Meltwater streams from snout of glacier dumps sedimentary material → till
  - silt and sand washed away downstream called outwash
- high bed-load component → streams generally braided
- outwash fans
  - large fan-shaped deposits
  - build up downstream of deposit

Eskers

- Glaciers may be drained by tunnels along floor of glacier
- many of these tunnels meander like a river
- glacier retreats →channel-fill sediment left behind → esker



Esker Wisconsin, USA

Lacustrine glacial deposits

Lakes in glacial areas (low energy)

- subsidence in land surface due to overlying ice sheet
- floors often accumulate laminated sediment
  - alternate light and dark layers
  - varves
- light layers
  - summer sediment input
- dark layers
  - lake frozen → little sedimentation
  - organic material

Varves, Missoula, USA

Lake varves, Missoula, Montana, USA

Icebergs and dropstones

- Icebergs
  - glaciers that enter the sea will break up to form icebergs
  - icebergs carry moraine offshore to deeper water where sea-floor sediments are fine-grained
- icebergs drop debris as they melt
  - boulders and pebbles
  - impact into fine-grained, soft sea floor sediments
  - deform underlying layering
  - "dropstones"

Glacial deposits and a dropstone

Glacial dropstone, Permian rocks, eastern Australia

Glacial erratic

- Exotic boulder dumped by retreating glacier
- can be transported large distances (hundreds of Km)
- examples around western Tasmania

Yeager rock,
Washington State,
USA

Periglacial environments

- Periglacial environments
  - cold areas surrounding, but not directly associated with glaciers
  - glacial material can be reworked in periglacial environments
- Permafrost
  - permanently frozen ground
  - surface layer (<2m) may melt in summer
  - overall precipitation low, so snow does not build up
  - can penetrate to depths of 700m

Permafrost, Fairbanks, Alaska

Periglacial soils

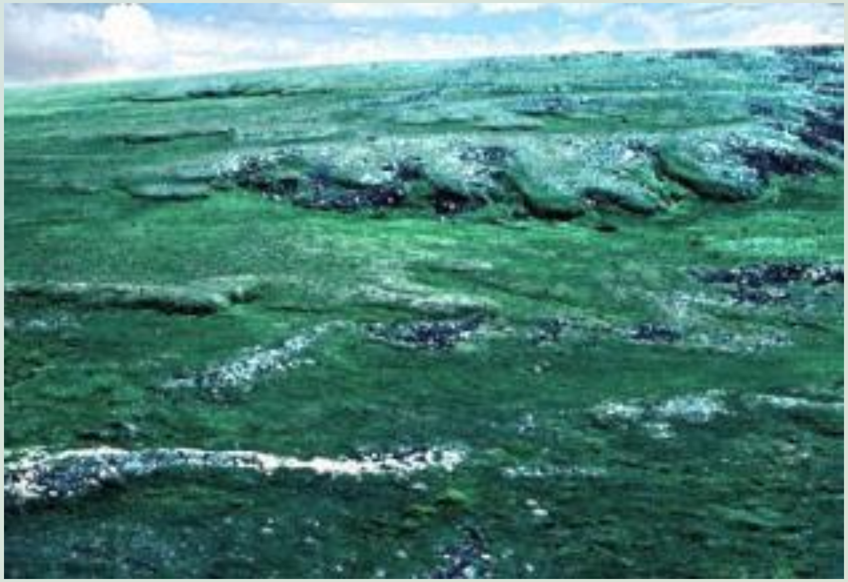
- Freeze/thaw cycles of surface layer

  - slow churning of rock and soil

  - moves material around, flow → solifluction

- frost heaving

  - growth of ice in soil causes vertical movement of material → bulges in soil



Solifluction lobes in soil

Siberia