Glacial Geomorphology

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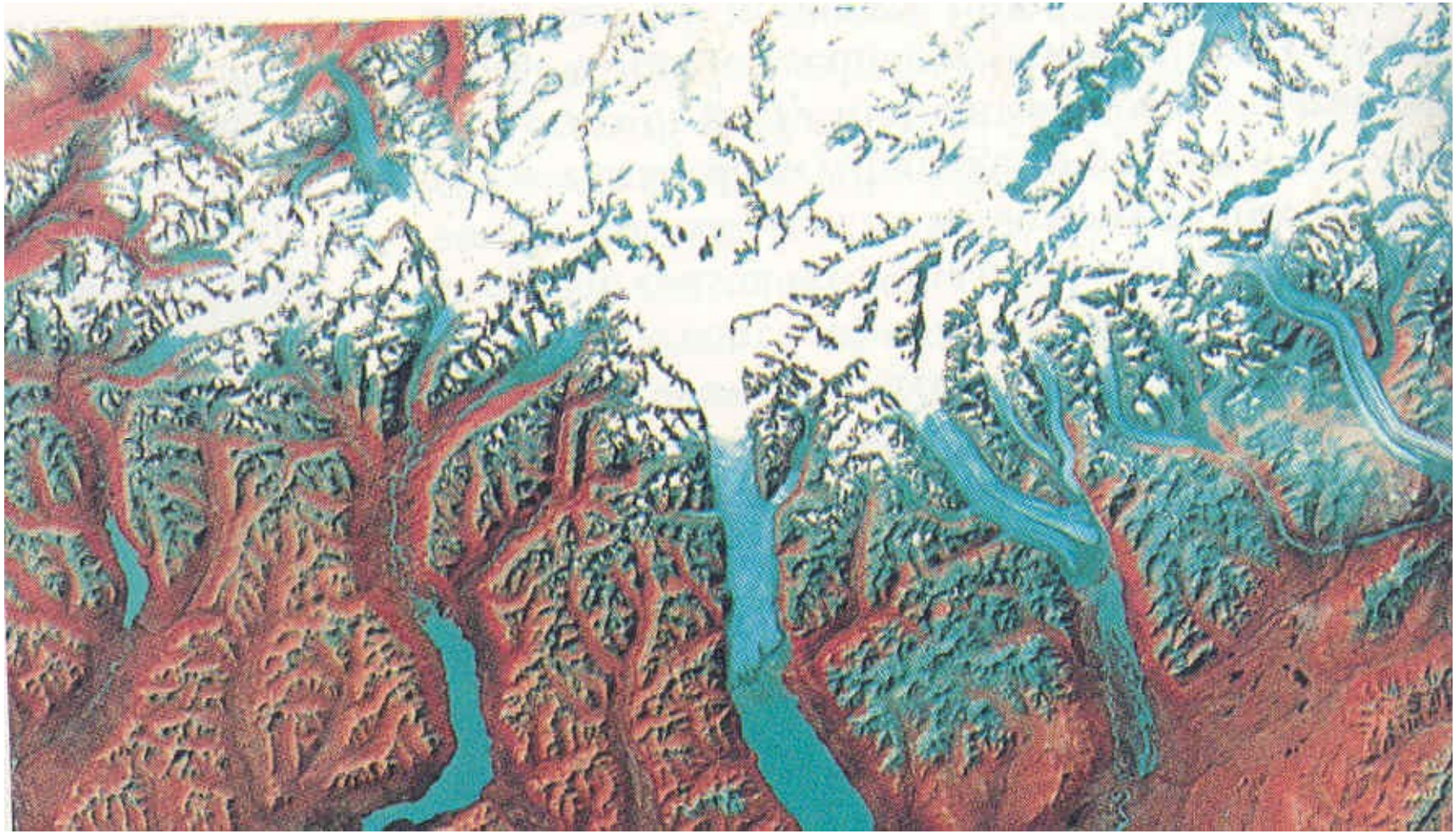
Glaciers

Glaciers are rivers or sheets of recrystalised Ice that survive all year along and move in response to their own weight and slope. They carve beautiful landscapes and deposits hills of sediment

Vatnajokull Glacier, Iceland

Valley glacier on Bylot Island

It is just off the northern end of Canada's Baffin island originate in the snow fields that almost completely cover the mountain peaks. Note that the snowline extends down almost to sea level. The main glaciers extend down from the highland as tongues of ice (blue). Note the glaciers, like river systems, consist of a main trunk stream and an intricate system of branching tributaries



Glaciers in the Himalayas show this continuing condition of retreat. The mountain glaciers in Bhutan shown here are shrinking and developing new lakes at their terminal - solid indications of diminishing glacial active in that region.

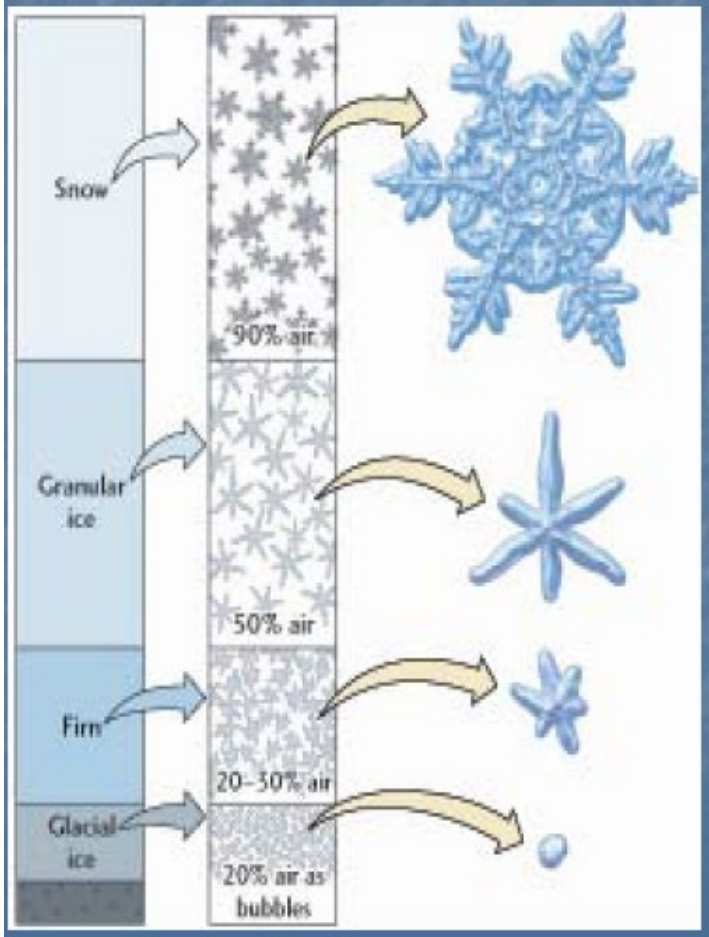
The image is a special, false-color image, using yellow, red, and blue filters, to enhance various types of ice and glacial zones.

It shows the thick ice cap (defined as a dome-shaped ice mass with radial flow) known as Vatnajökull, in south-central Iceland which has 43 outlet glaciers (light blue), many with lobate termini.

Areas in yellow-orange are vegetated, while reds associate with basaltic rocks and sparse vegetation.
Green in the ocean is sediment, and

black around the ice cap is a zone of ground soaking from glacial meltwater.

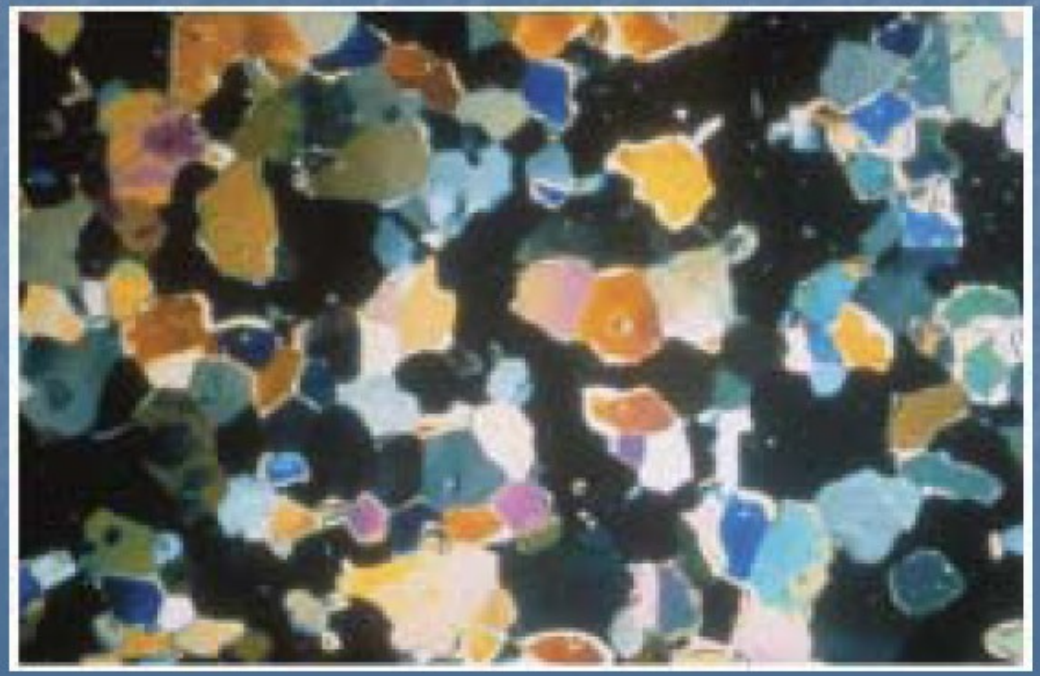
Glacial Ice



- Accumulates where snowfall in winter exceeds melting in summer
- When snow is greater than several meters thick it is compressed into a more compact form termed firn
- When the snow/firn layer is > 30m thick the material is compacted into pure ice

Glacial Ice

- Glacial ice will recrystallize under the pressure of the overlying snow/firn to form a polygonal texture (similar to granoblastic metamorphic rocks)



Glacier Formation

Large, long-lasting accumulation of snow & ice that develop on land

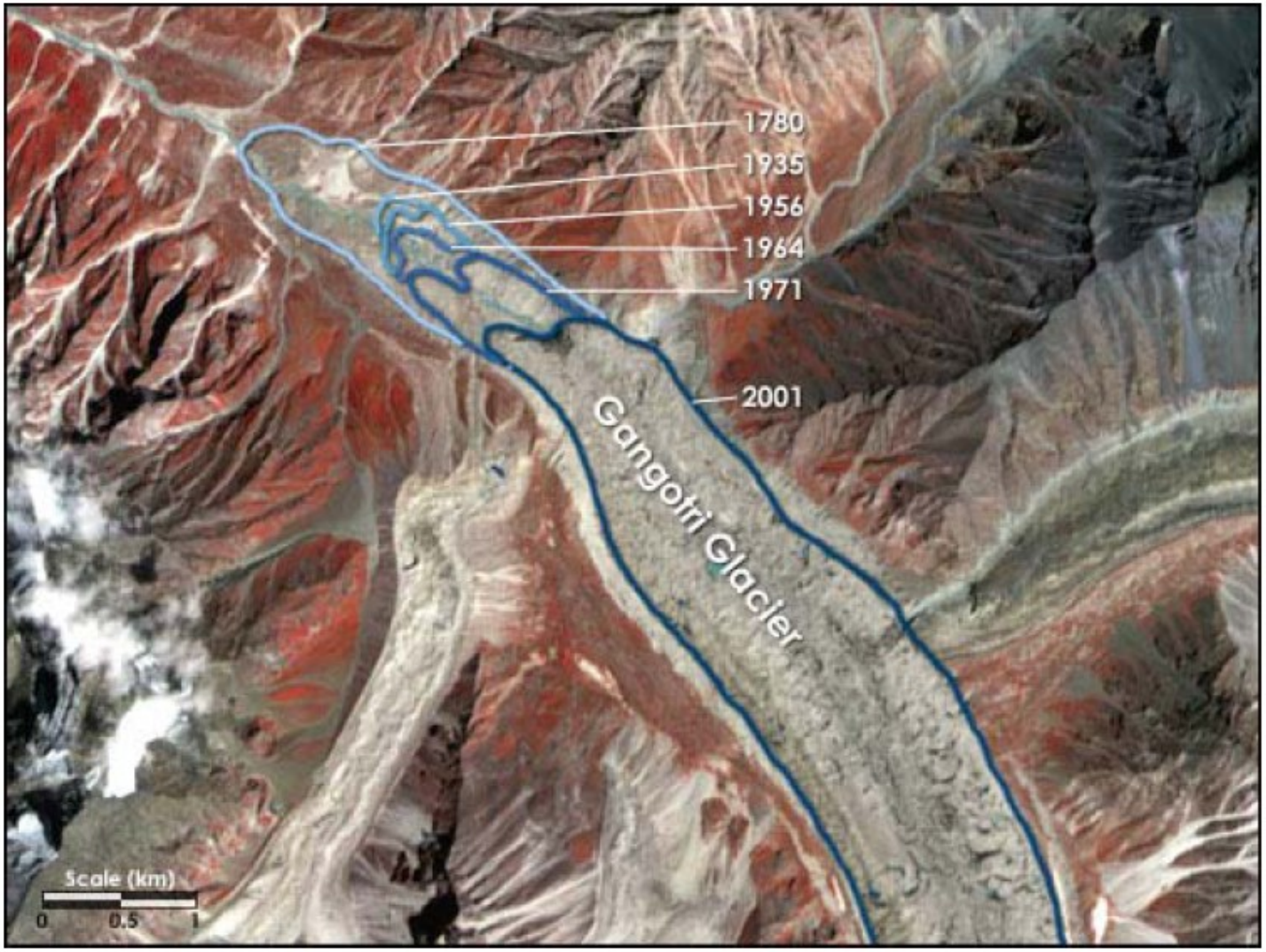
Time passes –ice mass begins moving due to pull of gravity

Periods of…

- ADVANCING (cold temps + moisture = accumulation)

- RETREATING (warm temps = melting)

Movement: Advancing & Retreating



Zones of Accumulation & Ablation

Zone of Accumulation

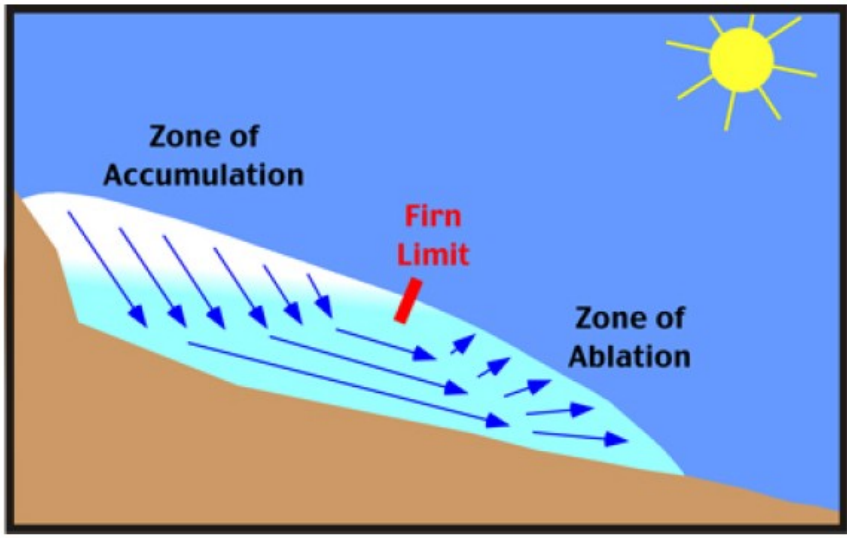
- Area where glacier is gaining precipitation
- Upslope –higher elevations

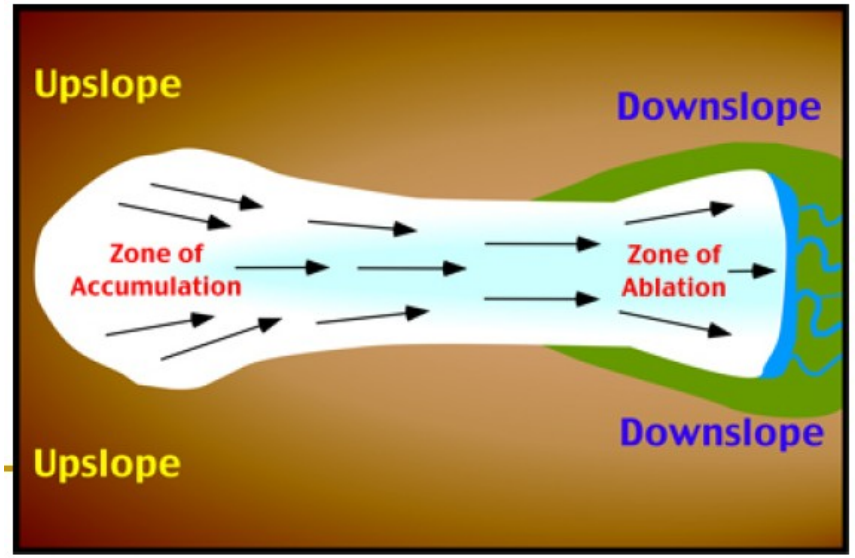
Zone of Ablation

- Area where glacier is melting
- Downslope–lower elevations

Sublimation

- Occurs when ice is directly changed into water vapor





Glacier Zones

Southwestern coast of Greenland

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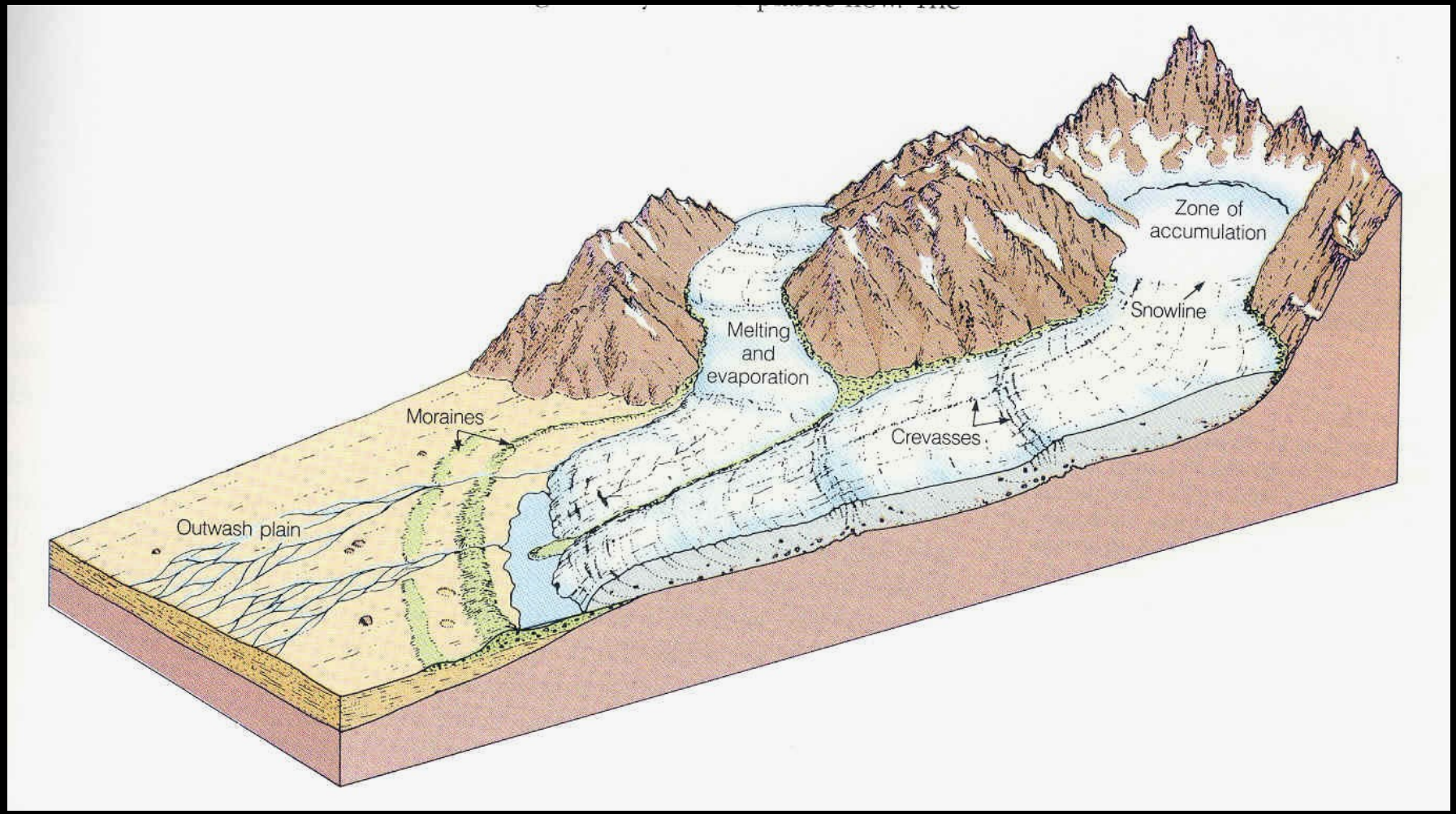
Ablation

Matanuska Glacier, AK. Foto: Lachniet (1997)

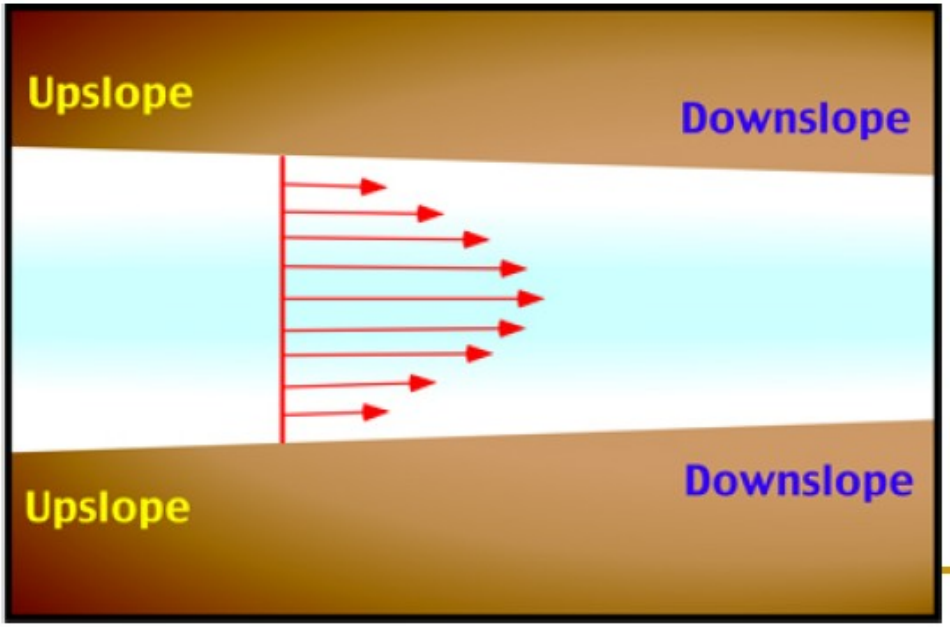
A Glacial system

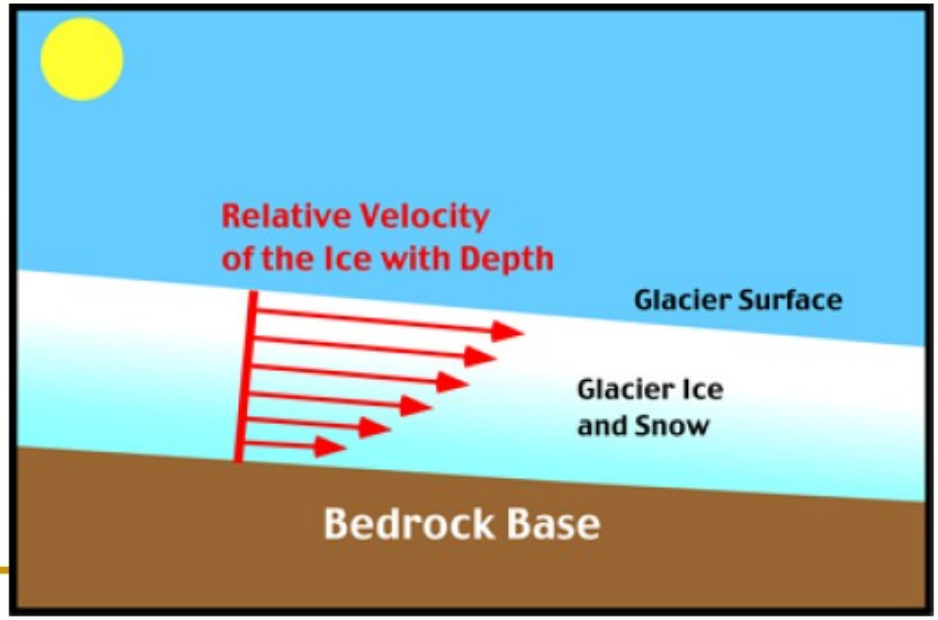


Movement of Glaciers

To be called “glacier”, mass of ice must be capable of MOVEMENT

- Movement within glacier is not uniform.
- Middle and top of glacier moves faster than sides and bottom.



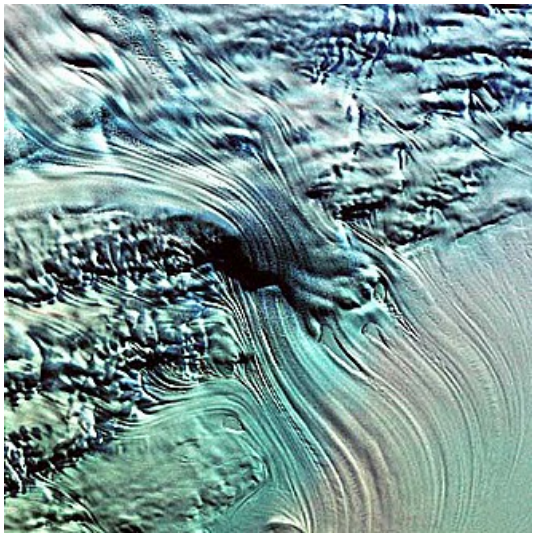


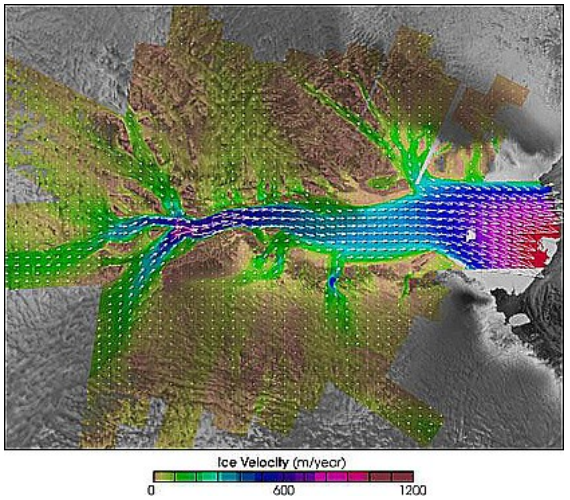
Glacial Movement

Plastic flow: **under the influence of gravity glacial ice will undergo plastic flow as much as several meters per year**

Basal slip: **under sufficient pressure the basal ice in a glacier will melt allowing the entire glacier to undergo basal slip up to a kilometer per year**

The largest and longest glacier in the world is the Lambert Glacier, in northeastern Antarctica (Australian sector), which meets the sea at the Amery Ice Shelf. Its length is given as 403 km (250 miles); it width reaches to 64 km (40 miles).





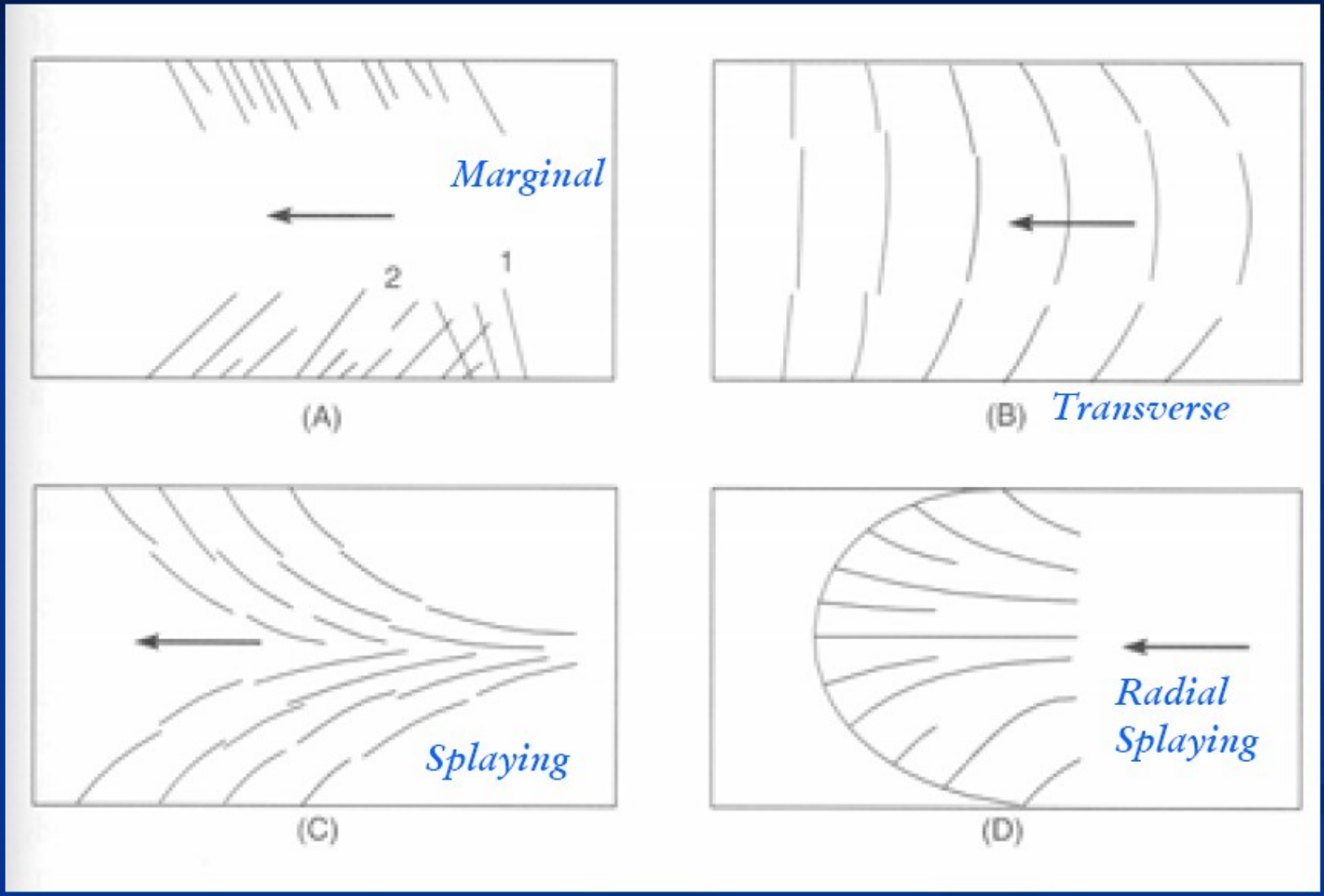
Three space images: the first shows part of the glacier in a Landsat image; the center is a perspective view made using DEM data; the third displays rates of flow determined from radar data taken over an extended period:

Crevasses

- **Crevasses are cracks in the glacier ice**
- **Form at low confining pressures**
- **near the glacier surface ice is brittle**
- **Seracs are a form of crevasses that commonly form at icefalls**

- Longitudinal crevasses develop in areas of compressive stress
- Transverse crevasses develop in areas of tensile stress
- Marginal crevasses occur when the central portion of the glacier flows faster than the outer edges.

Crevasses

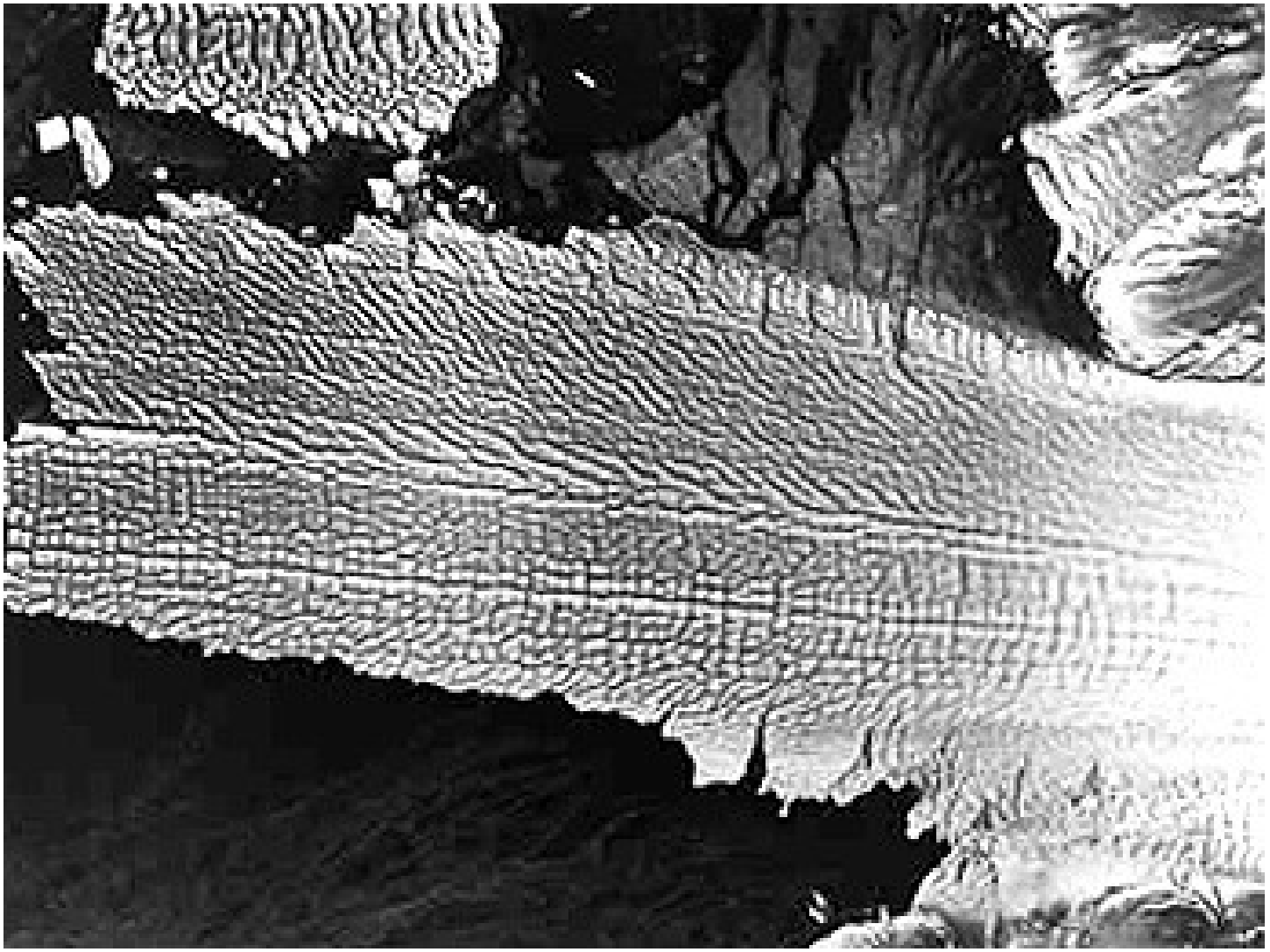


From Ritter et al., 2002. Process Geomorphology, Fourth Edition

Crevasses in a glacier, Alaska

Crack or fissure in a glacier resulting from stress due to movement, Glacial crevasses may be 20 m wide, 45 m deep and several hundred meters long. Longitudinal crevasses develop in areas of compressive stress, transverse crevasses develop in areas of tensile stress, marginal crevasses occur when the central portion of the glacier flows faster than the outer edges. Jagged ice pinnacles may form where crevasses intersect at the glacier terminus

This JERS-1 SAR (radar) image of an Alaskan glacier brings out the details in the cracking of the ice as the entire mass moves slowly down gradient.



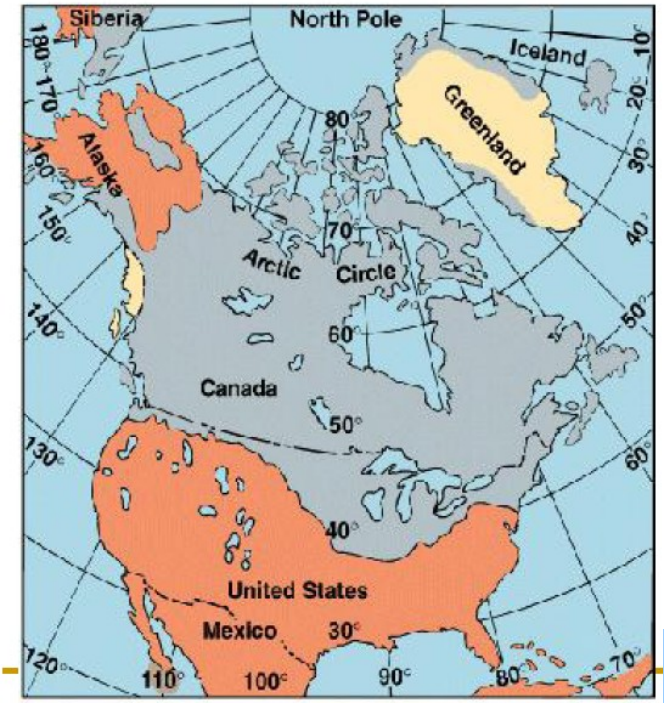
Glacial Mass Balance

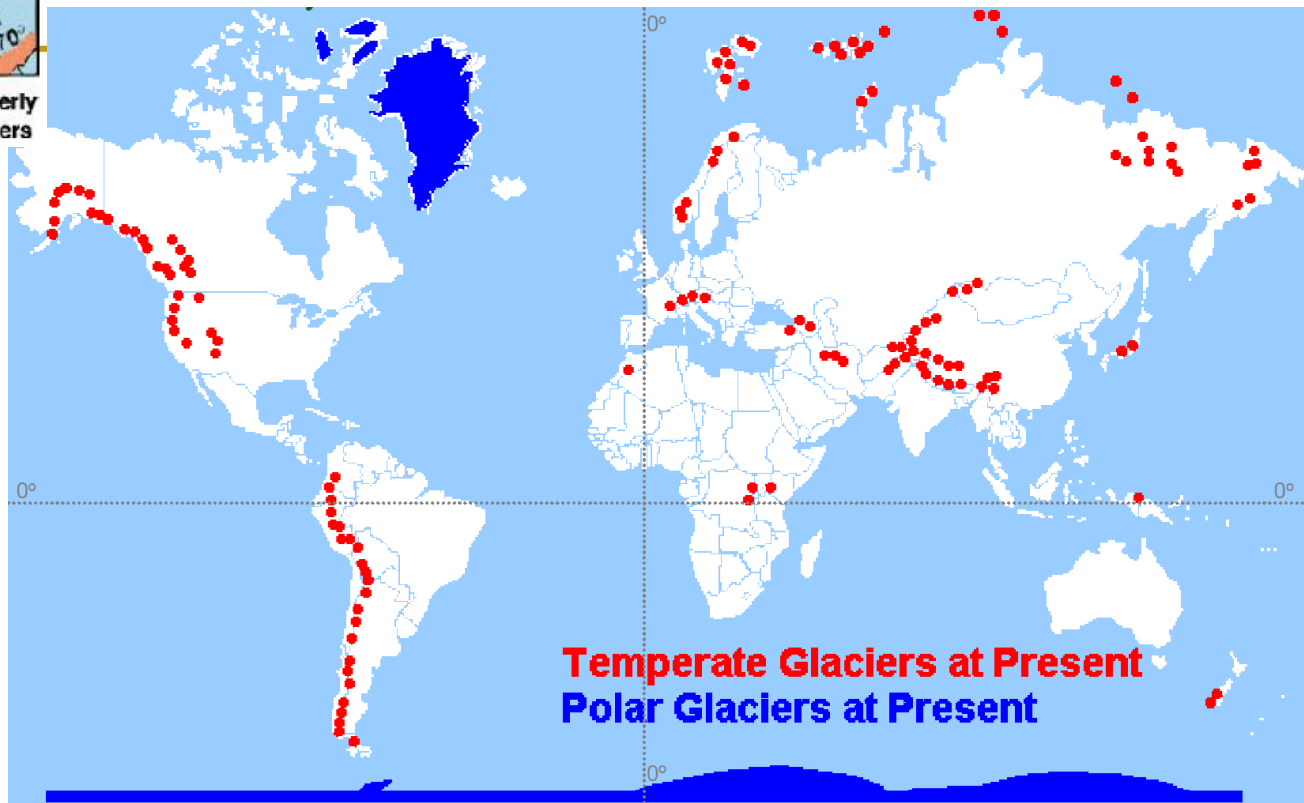

Measuring thickness in a crevasse

Calculated by the difference in amount of snow accumulated (winter) and the snow melted (summer).

Snow accumulated is less than Melted snow, mass balance is positive and the glacier has increased in volume.

Melted snow is more than Snow accumulated, mass balance is negative and the glacier volume decreased.


Siberia
North Pole
Iceland
Greenland
Alaska
Arctic
Circle
Canada
United States
Mexico
Existing glaciers
Land areas formerly covered by glaciers


Temperate Glaciers at Present
Polar Glaciers at Present

Categories of Glaciers

Continental Glacier:

- Large ice masses that cover significant portions of continents and are a mile or more thick

Largest type: only 2 exist

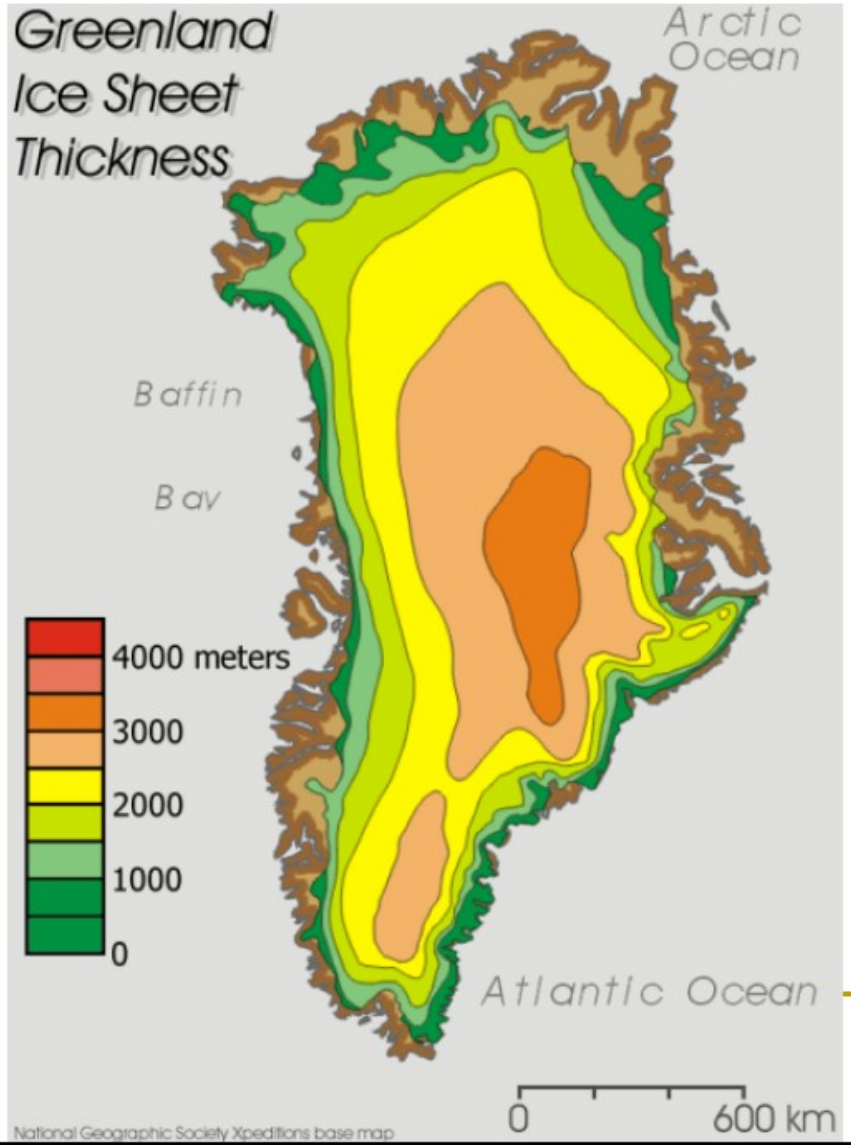
- ANTARCTICA and GREENLAND
- Surface coverage of at least 2Million sq. miles

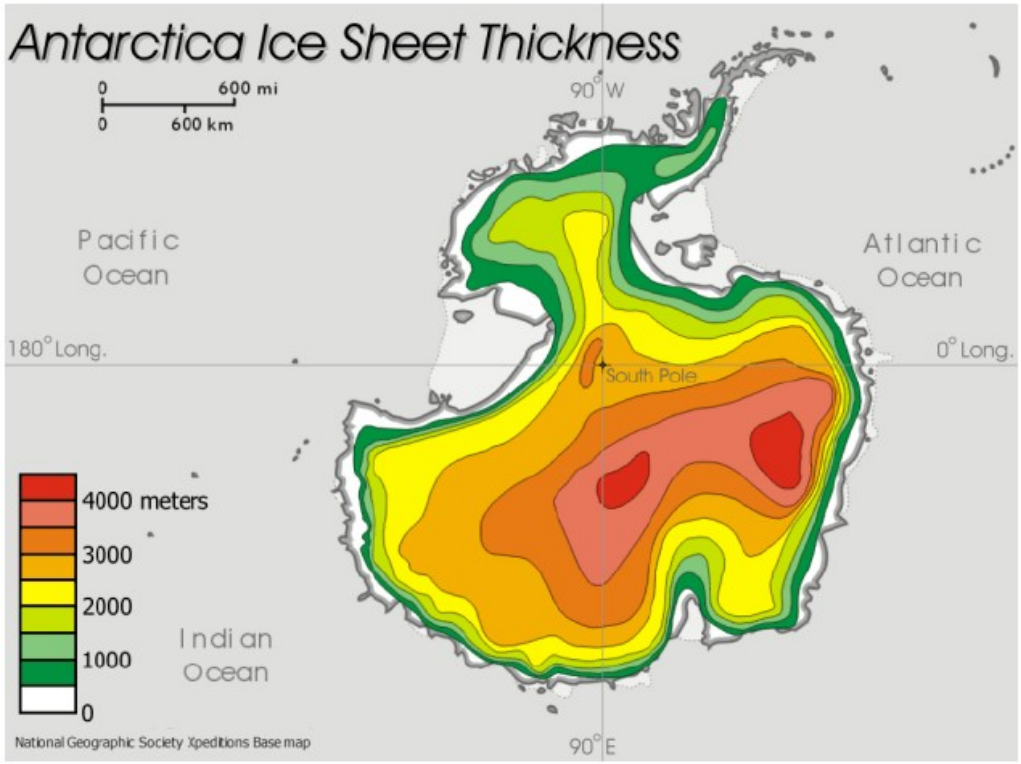
Mountain/Alpine Glacier

- Occupies a U-shaped valley on a mountain
  - 2 MYA (Pleistocene), max extent: 1/3 land covered
  - Now: 10% land covered
  - 96% glacial ice is tied up in Antarctica & Greenland

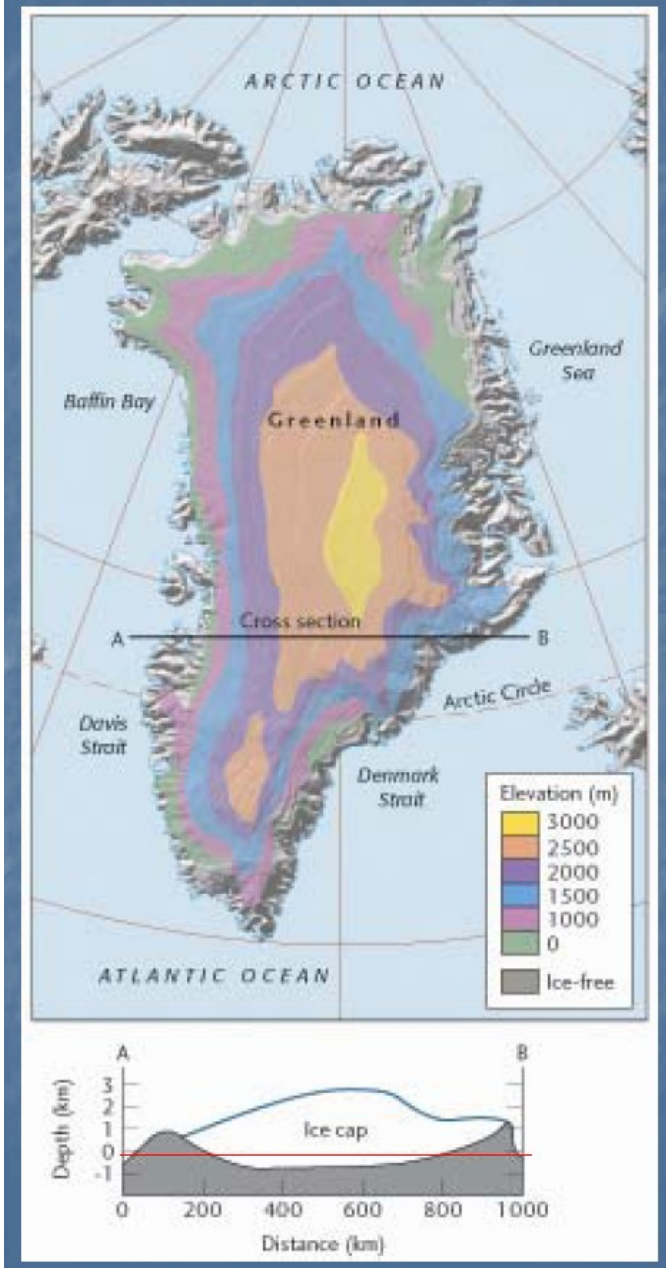
Continental Glaciers

Greenland & Antarctica





Continental Glacier



- Thick ice masses actually depress the lithosphere below sea level

Glacial Processes

1. **Erosion**

   - **Erosion is possible due to presence of till (Combination of all sizes of sediments (pebbles to boulders) carried within glacier and eventually deposited).**

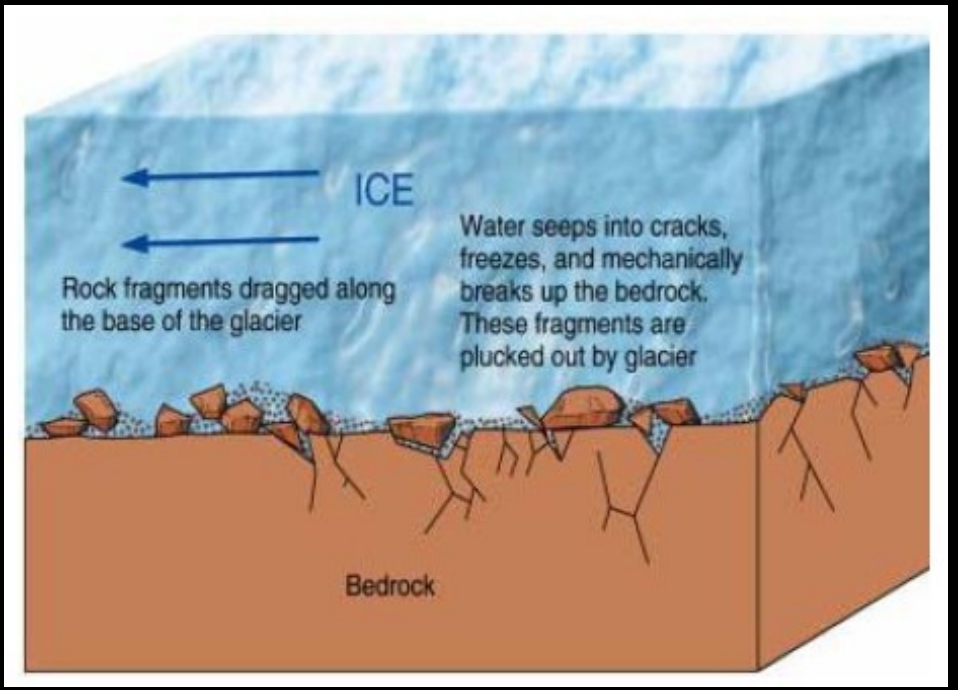
2. **Transportation & Deposition**

3. **Glaciofluvial**

Glacial Erosion

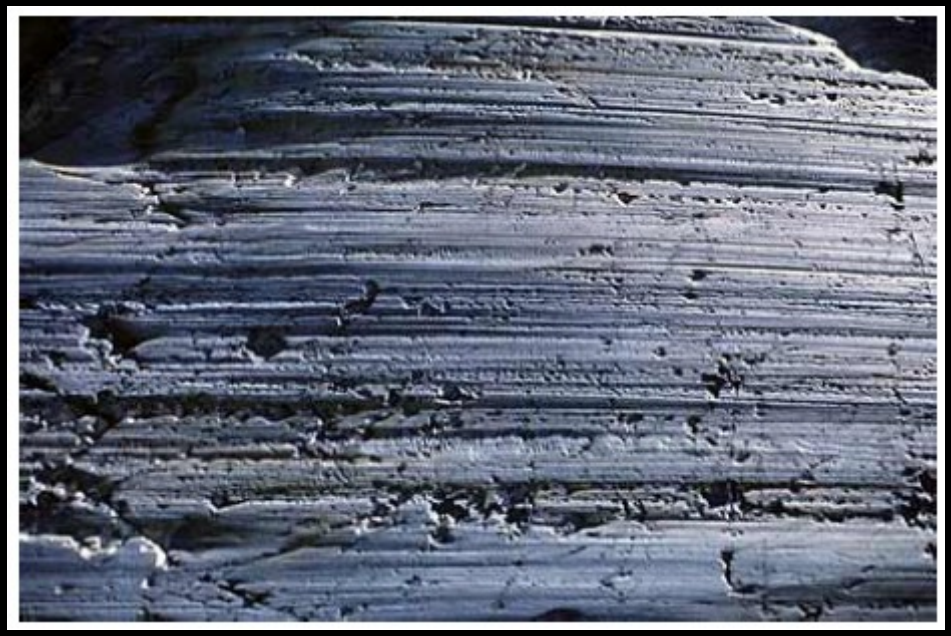
❖ Plucking

- Water gets in cracks, freezes, lifts up bits of rock and carries them in the glacier itself
- Leaves a blocky and irregular surface



❖ Scouring

- Abrasive action of rocks within glacier as glacier moves over surface
- Leaves striated surface
- Enough scouring creates a polished surface



Glaciofluvial

Meltwater deposit materials far away from the glacier

Braided streams are formed –think of all that till moving inside the glacier, and what happens to it as it is carried by meltwaters.

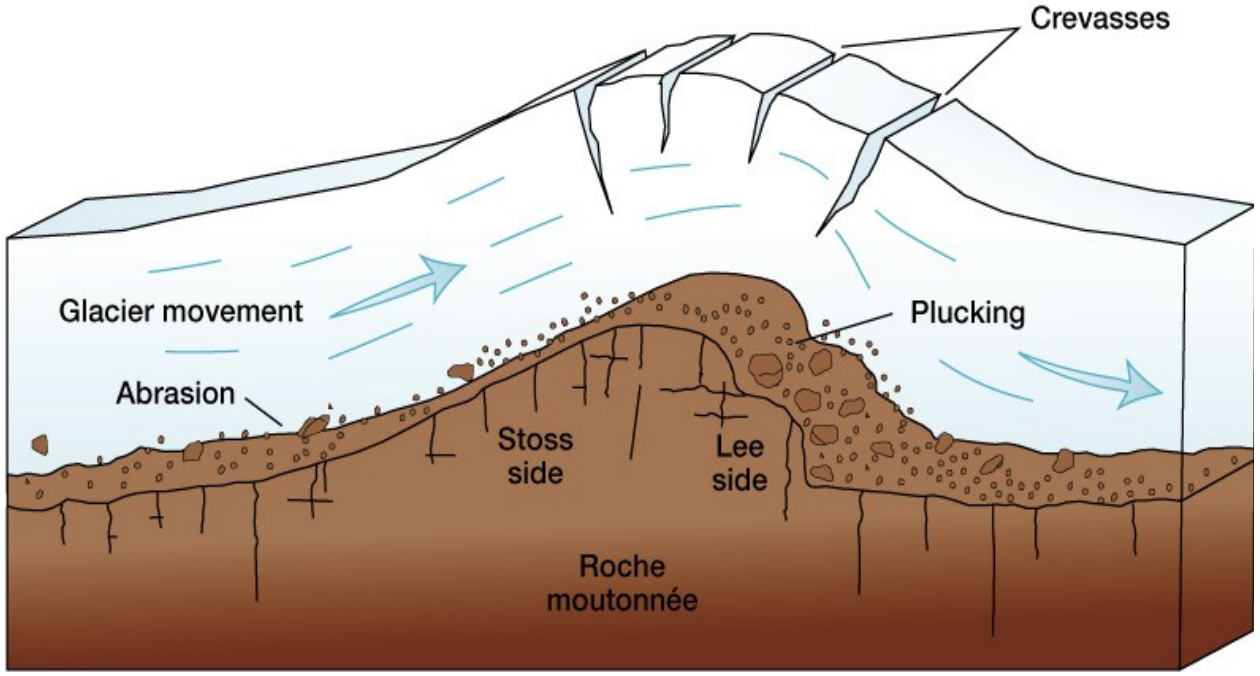
Glacial Transportation & Deposition

- Debris within glacier = transported
- Debris ahead or to sides of glacier = deposited
- Moraines form when till gets pushed into linear piles (heap) by the movement of a glacier.

EROSIONAL FEATURES OF GLACIERS

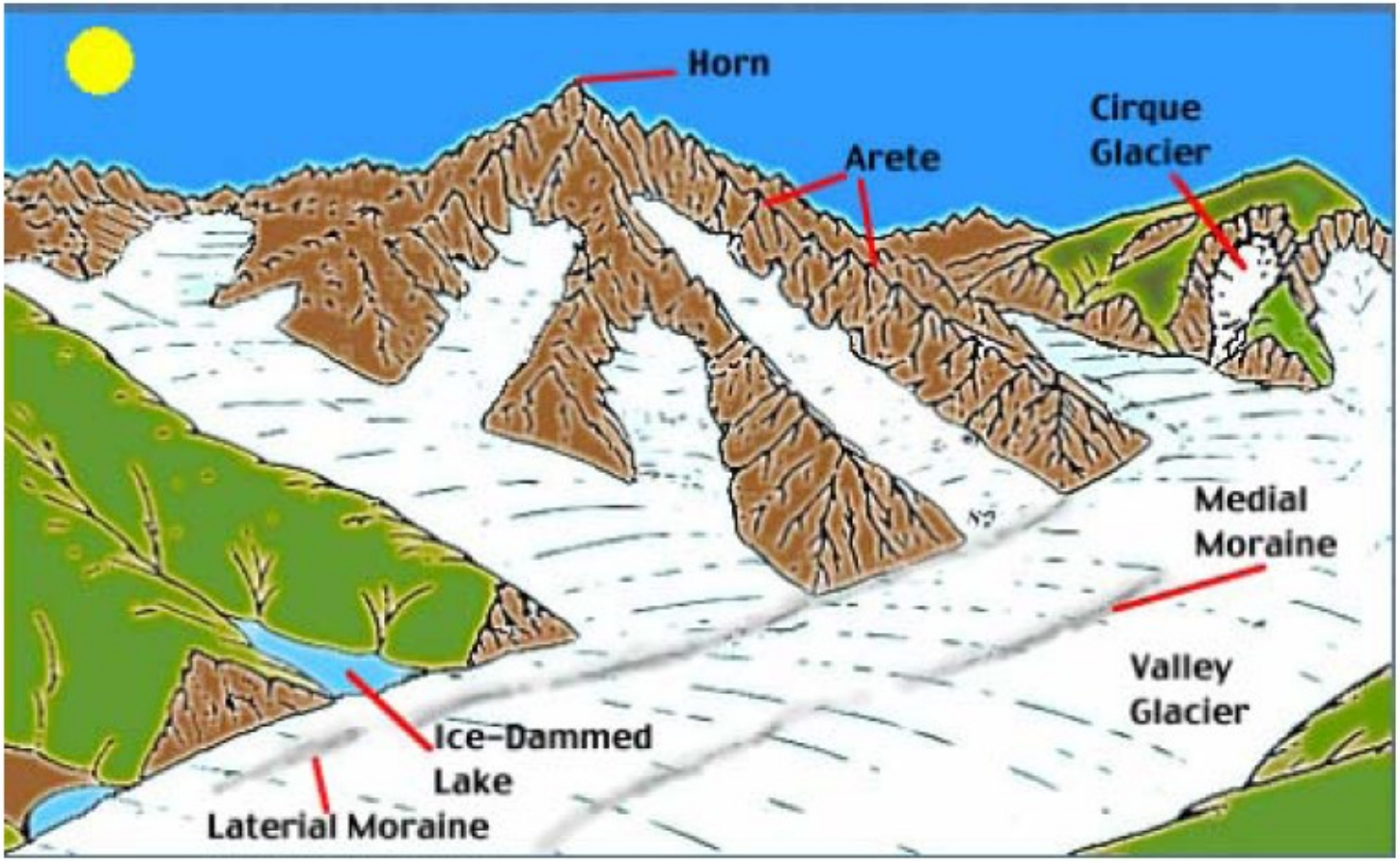
Roche moutonee

A glacially eroded hill that becomes elongate in the direction of flow and asymmetric; glacial rasping smoothes the upstream part of the hill into a gentle slope, while glacial plucking erodes the downstream edge into a steep slope.



Landforms due to Erosion in Mountain (Valley) Glaciers

- Cirque
- Tarn
- Horn
- Arete
- Glacial Valley
- Hanging Valley
- Paternoster Lakes

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Pointer 31°03'59.20" N 79°21'08.67" E
Streaming 100%
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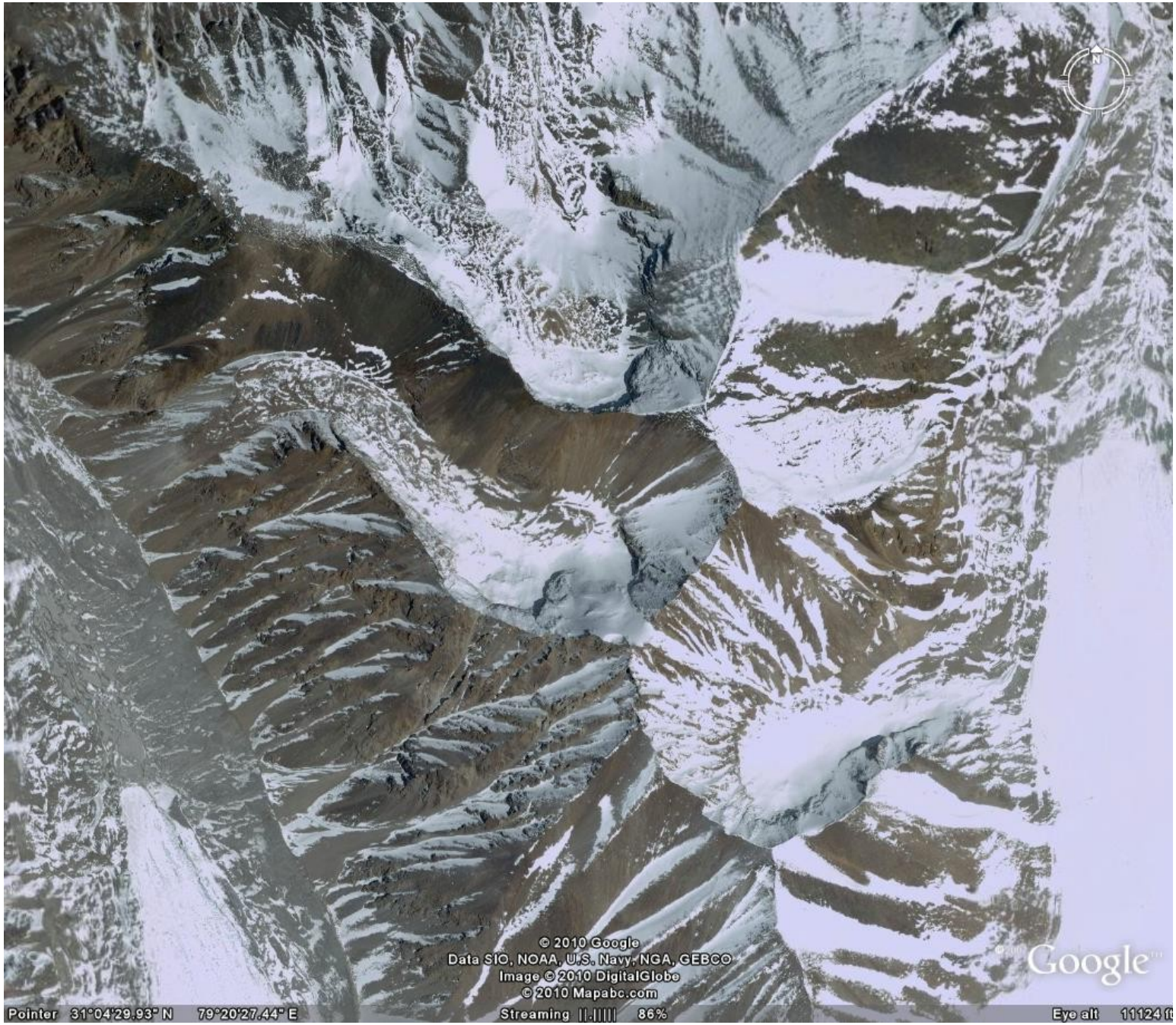
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Image © 2010 DigitalGlobe
© 2010 Mapabc.com
Google
Pointer 31°04'29.93" N 79°20'27.44" E
Streaming 86%
Eye alt 11124 ft

Erosional Features: Cirques

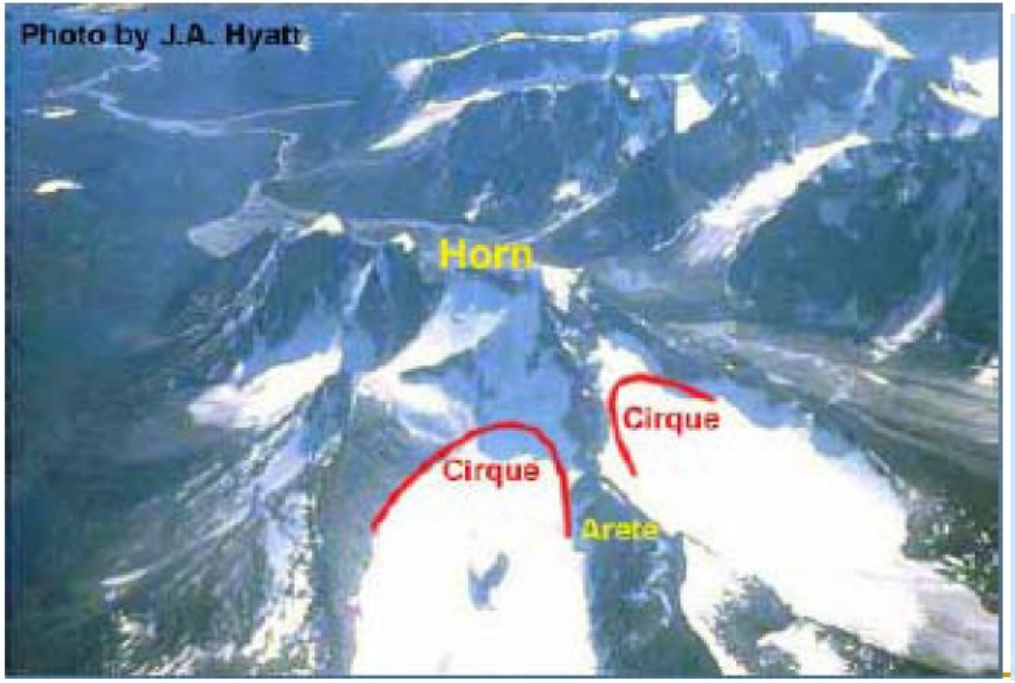
- Bowl-shaped depression
- Area where snow first accumulates and modifies into glacial ice (called Cirques Glacier)

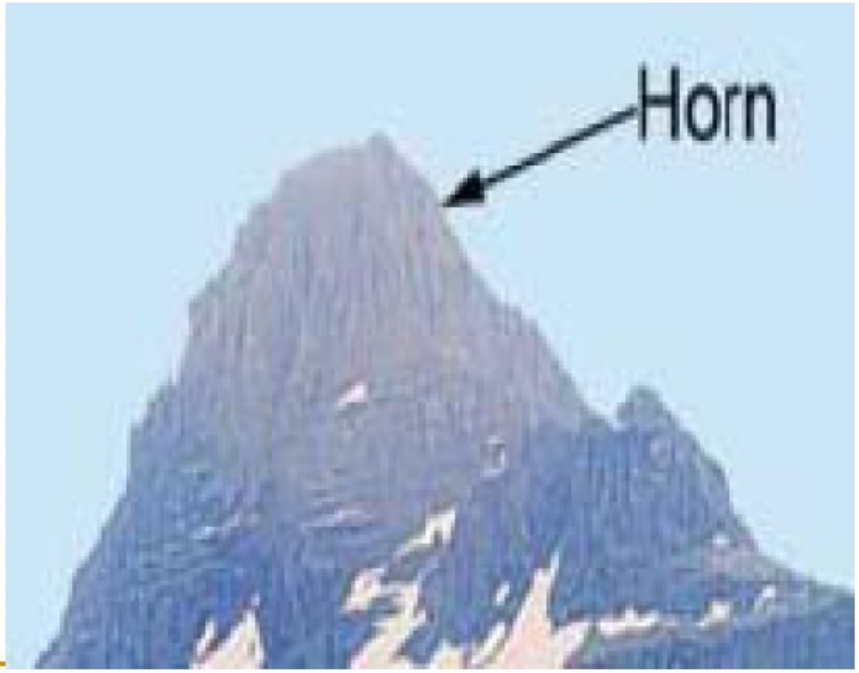
Erosional Features: Tarns

- After a glacier is no longer present, a lake may form in a cirque

Erosional Features: Horns

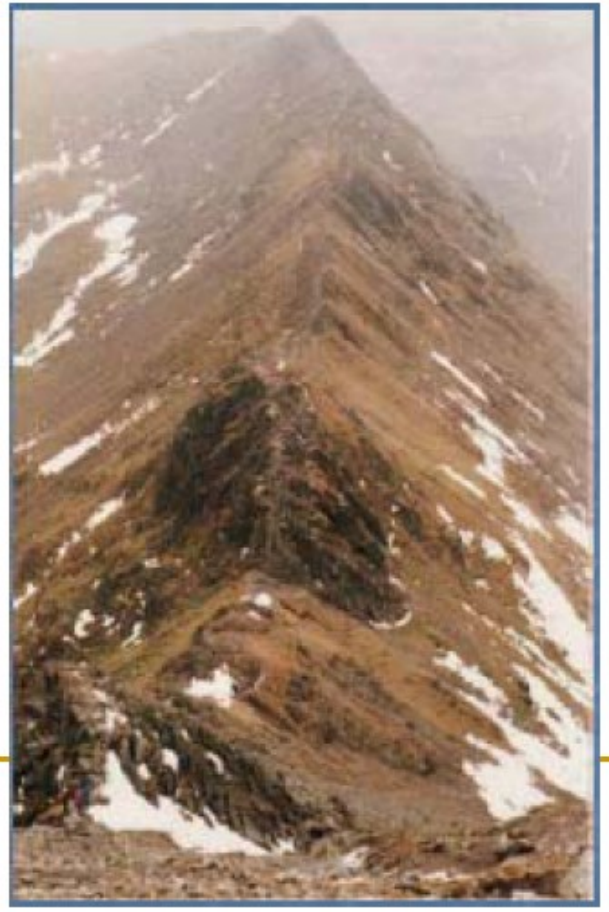
- **Pyramidal peak that forms when cirques chisel a mountain from 3+ sides**





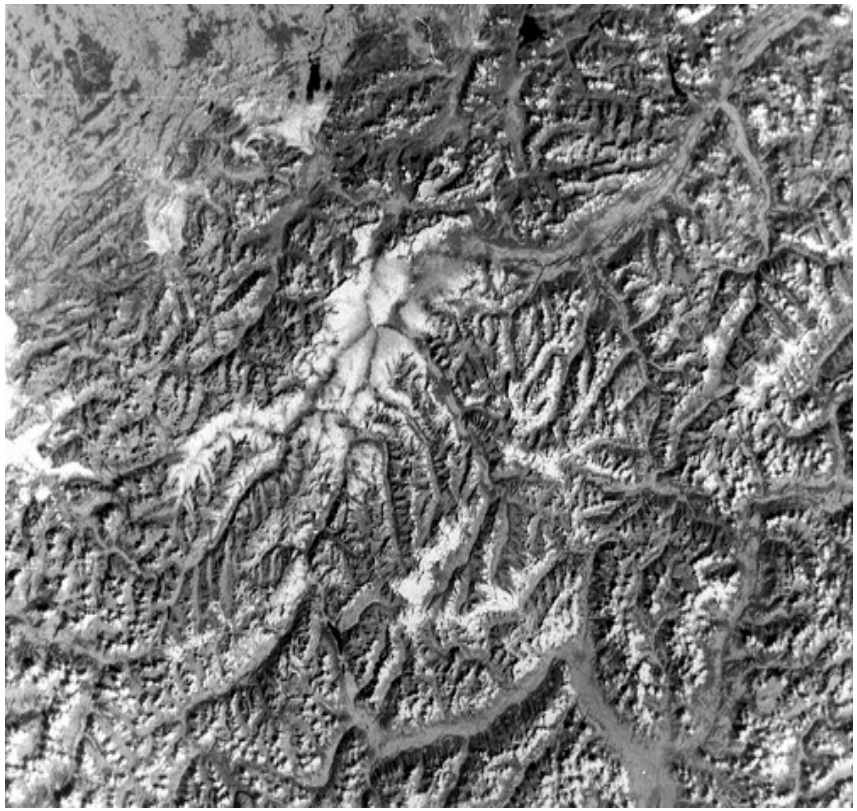
Erosional Features: Aretes

- Narrow ridge : Formed when two glaciers move down valleys and erode the area between them into a ridge



Erosional Features: Glacial Valley

- Valleys become deeper & wider over time
- Guide the path of glacial ice flow
- U-Shaped

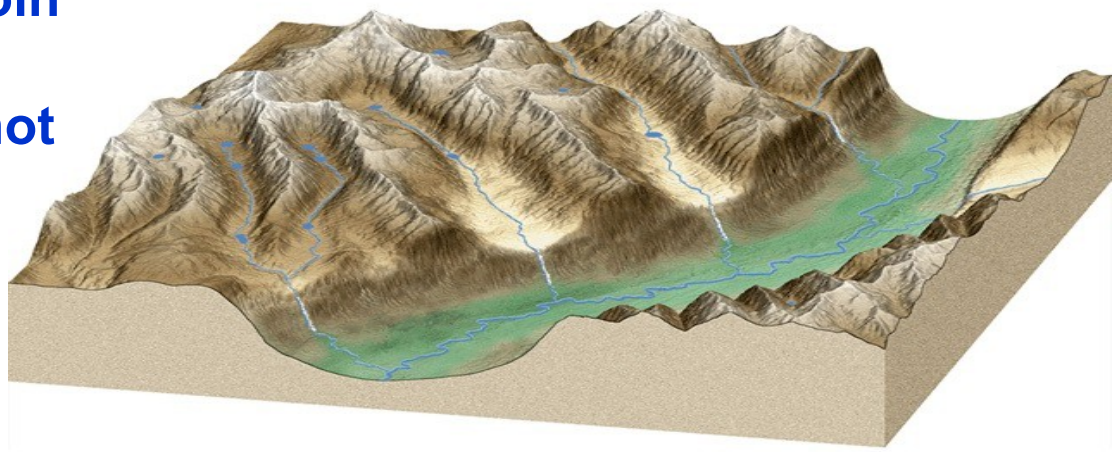


This Landsat scene shows widened valleys in the alpine region of that country

U-Shaped Valley in Scottish Highland

Erosional Features: Hanging Valley

- When smaller valleys join with larger glacial valleys, the floors are not at the same elevation
- Waterfalls are often present here



Fjord : A deep, glacially carved, U-shaped valley flooded by rising sea level.

This partial Landsat scene in the Trollaskagi region of northwest Iceland provide a post-ice view of an ice-sculpted mountainous area where glaciers, now gone, have left conspicuous troughs (wide valleys) with intervening ridges now sharply creased into aretes.

Several large fjords are formed where seawater has encroached into larger glacially-scoured lowlands.

Knik Arm - Fjord

Photograph: Matthew Lachniet

Erosional Features: Paternoster Lakes

- Chain of tarns that are formed when a valley "steps" down
- Lakes are all connected by streams and/or waterfalls

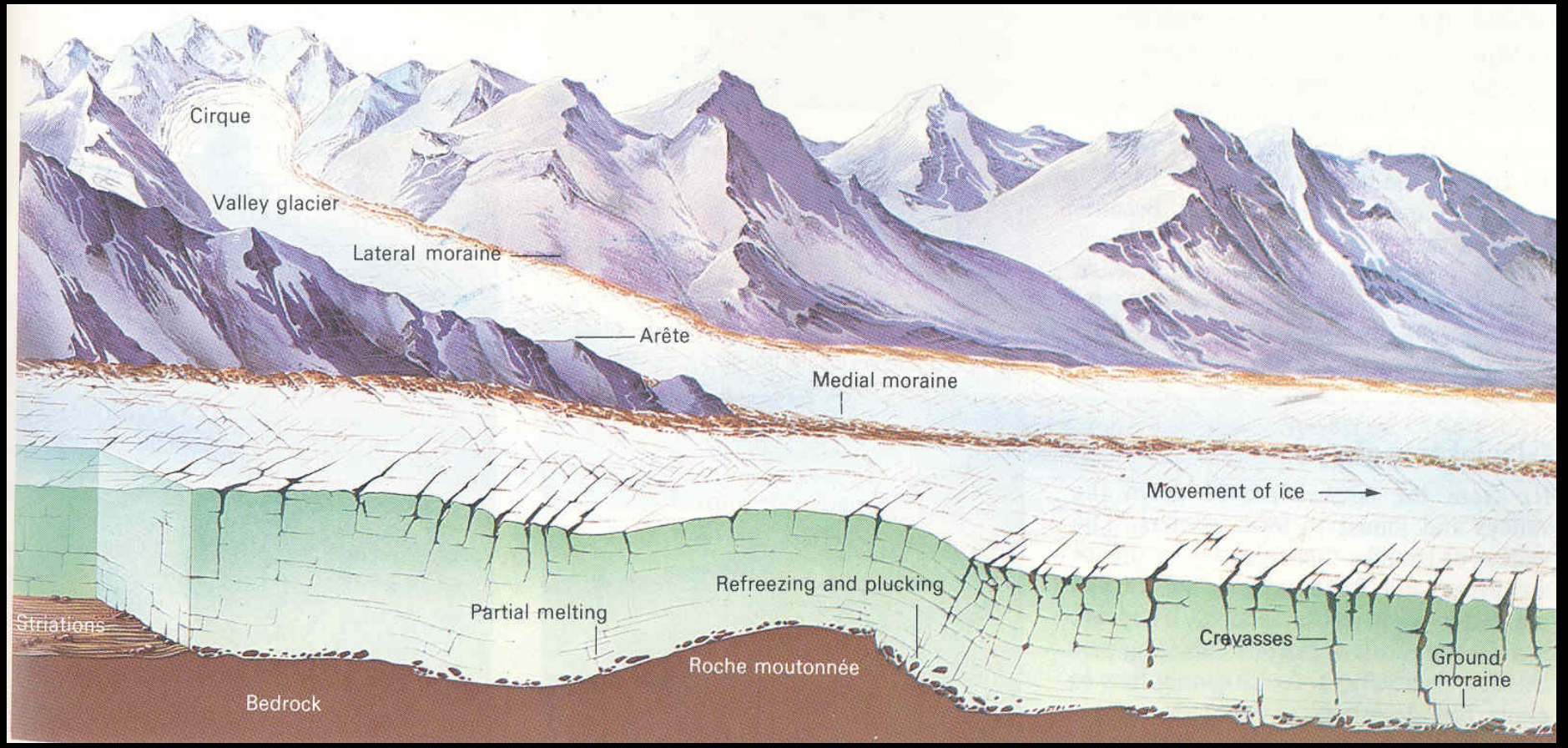
DEPOSITIONAL FEATURES OF GLACIERS

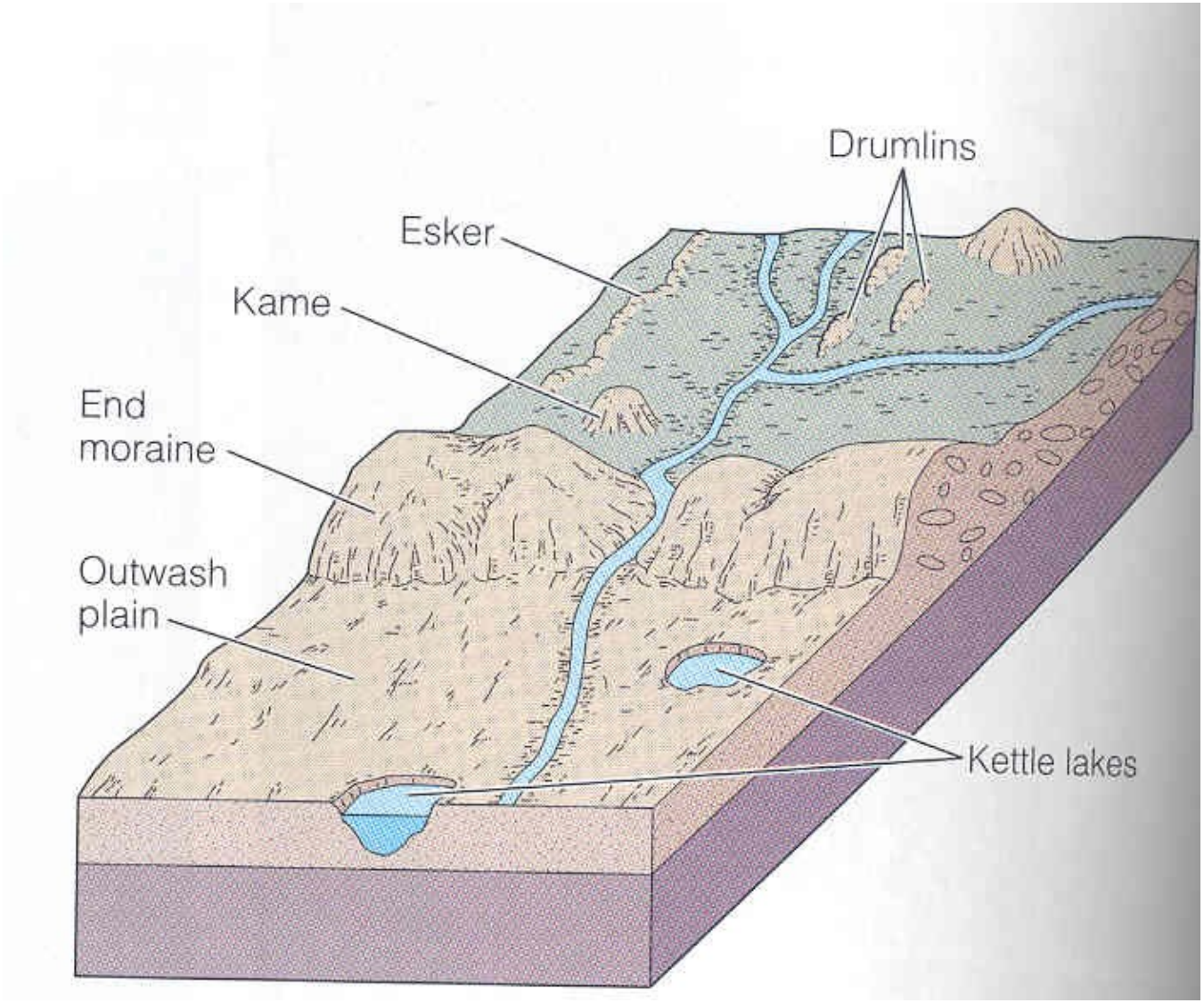
Continental Glaciers

Landforms

All formed by **deposition** of materials

- **Moraines**
- **Kames**
- **Esker**
- **Kettles/Kettle Ponds**
- **Braided Outwash Streams**


Cirque
Valley glacier
Lateral moraine
Arête
Medial moraine
Movement of ice
Refreezing and plucking
Partial melting
Striations
Crevasses
Roche moutonnée
Ground moraine
Bedrock


Drumlins
Esker
Kame
End
moraine
Outwash
plain
Kettle lakes

Moraines: **A strip of debris or linear body of debris formed by the glacier.**

- **Numerous types of moraines, Two are associated with continental glaciers**

1. **Terminal Moraine**
   marks the maximum extent of the glacier

2. **Recessional Moraine**
   develops behind the terminal moraine as the glacier retreats

Depositional Features: Moraines

A strip of debris along the margins of a glacier.

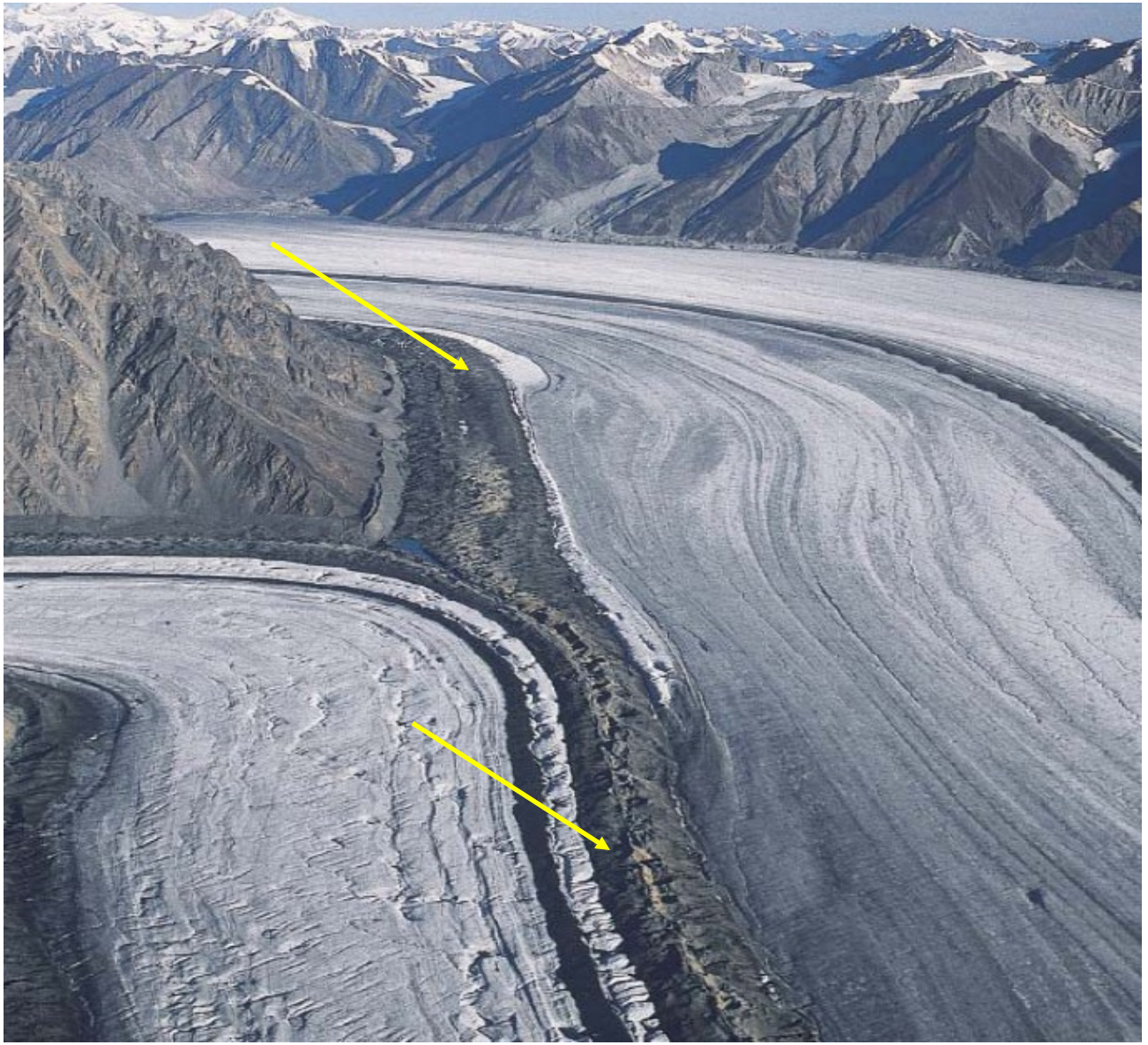
Lateral Moraines

A strip of sediment in the interior of a glacier, parallel to the flow direction of the glacier, formed by the lateral moraines of two merging glaciers.

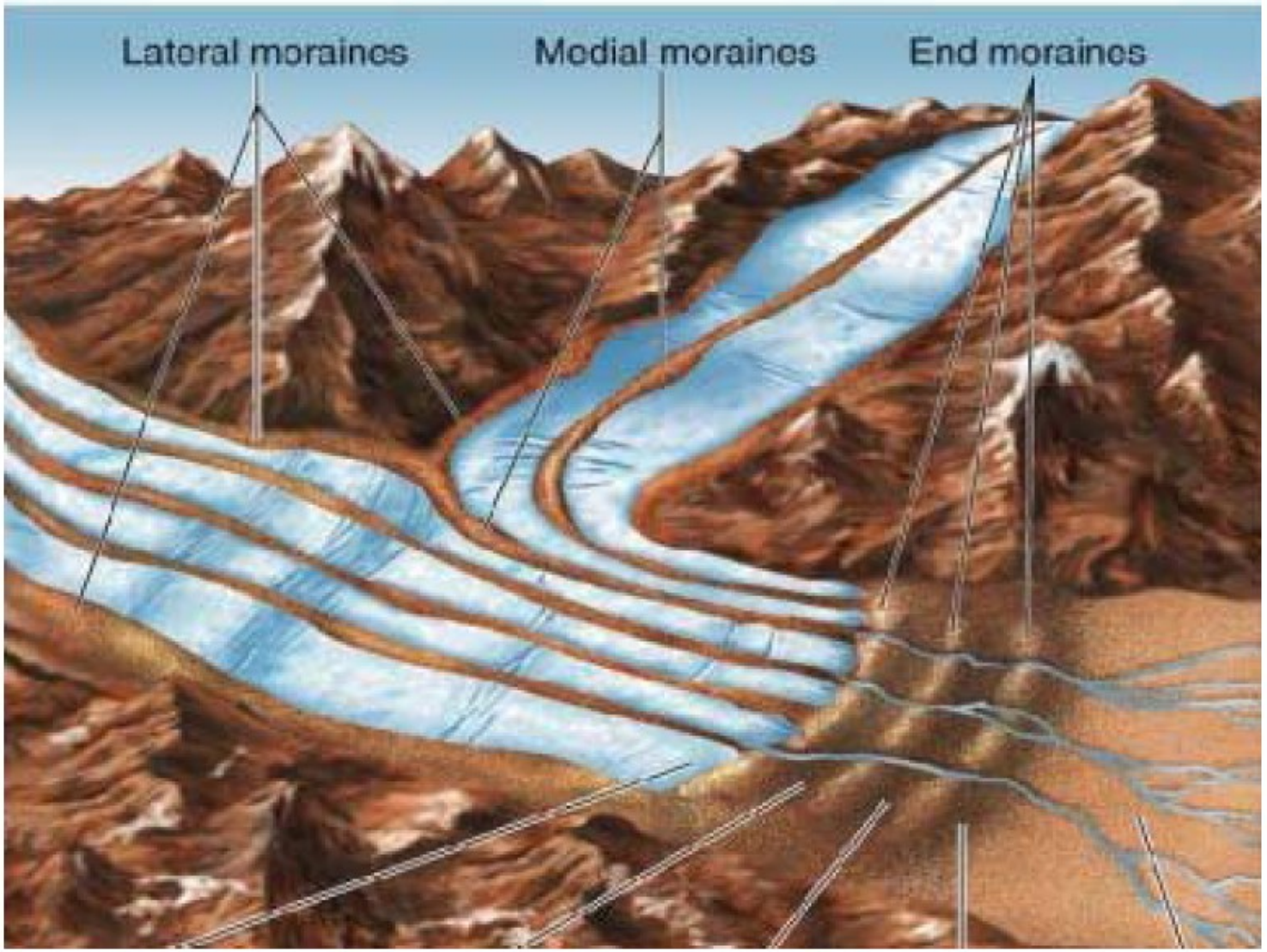
Medial Moraine

Will often form when two glaciers meet and continue down a valley

Lateral and Medial Moraines



“End moraines”are more commonly called “Terminal”and “Recessional”moraines.

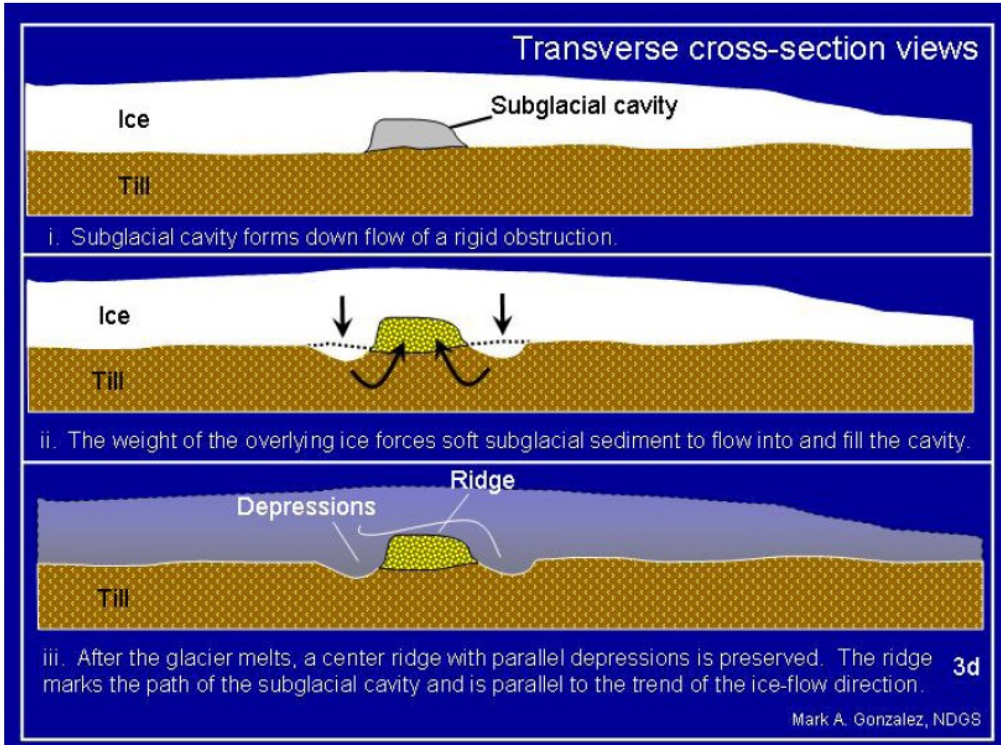


Glacial Till

- Sediment transported and deposited by a glacier
  - ❖ Poor sorting
  - ❖ bimodal: fines from abrasion; coarse grains from plucking
  - Usually lacks stratification
  - Cobbles exhibit striations and facets

Depositional Features: Kames

- Steep-sided, conical hill of debris that originally collected in a hole in the glacier.



Depositional Features: Erratics

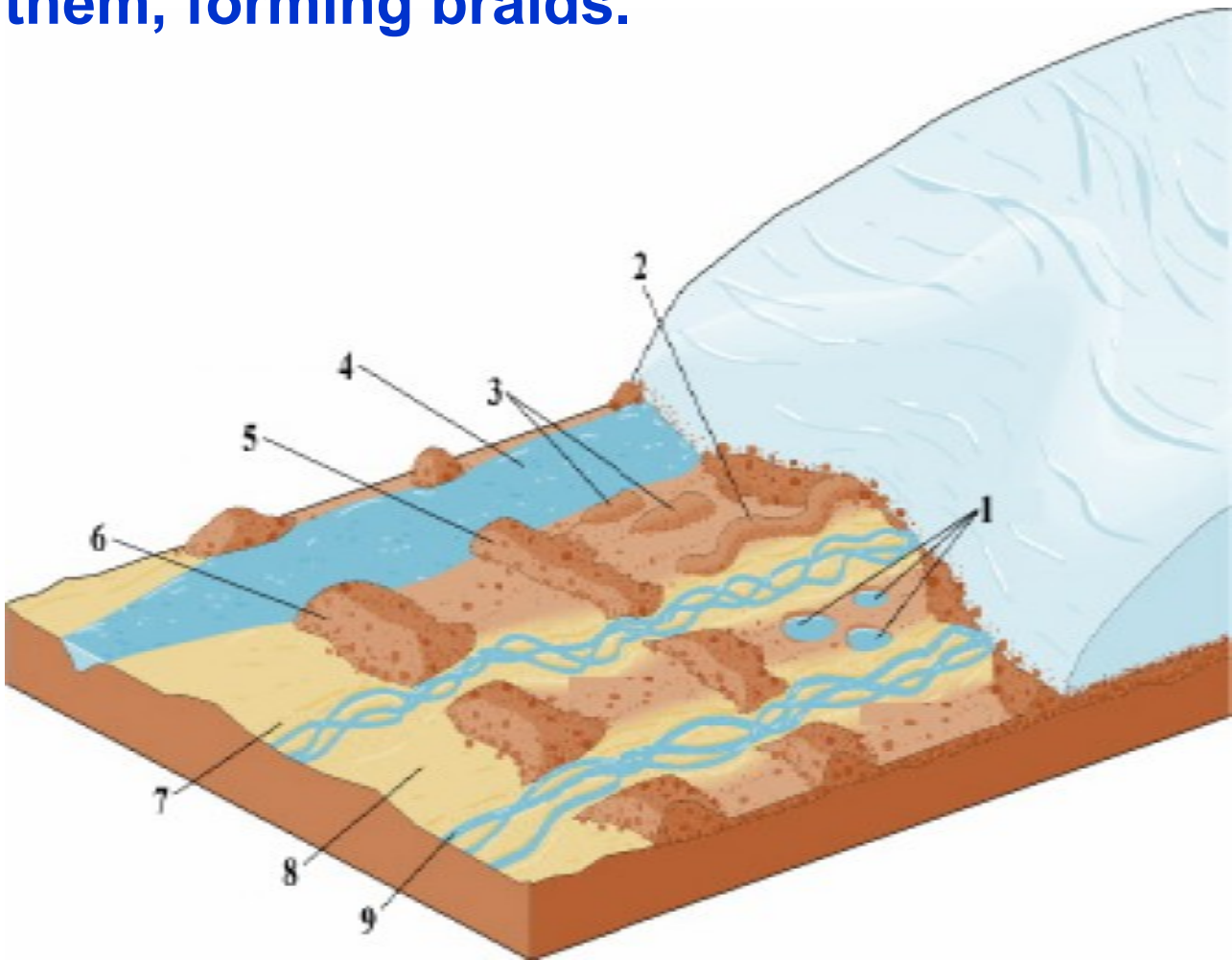
- Boulders that are carried far from their place of origin by a glacier

Depositional Features: Kettles

- Large chunks of ice leave a depression in the landscape because
  - Isolated ice is surrounded by till (which becomes part of the landscape). Ice melts – leaving a “depression”.
  - If filled with water,called “kettle lakes”

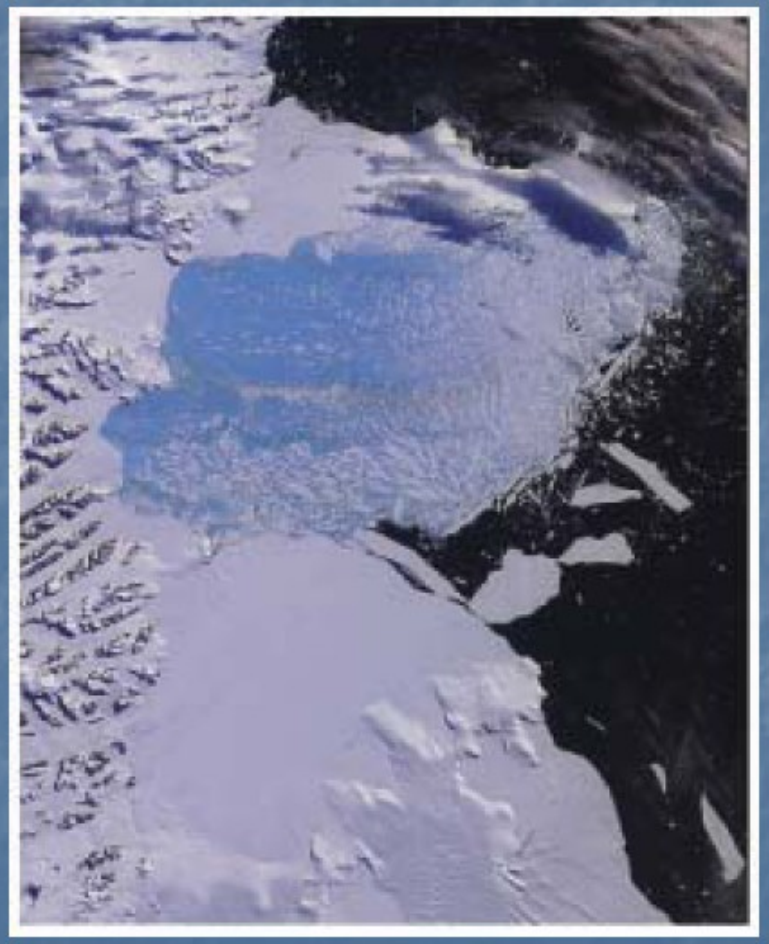
Depositional Features: Glacial Outwash Meltwater

Braided streams form when glacial meltwater passes through the moraines and picks up till. It will eventually drop this till into channel bars and begin flowing around them, forming braids.



Ice Shelves

- Large portions of continental glaciers that are floating in the oceans



Varves :- are thin, alternating layers of light and dark sediment deposited in a glacial lake.

A layer of relatively coarse grained, light colored sediment accumulates during the spring and summer runoff.

During the winter, when the lake is frozen over, fine, dark mud settles to form a dark layer.

Each set of light and dark layers therefore represents a year's accumulation

'Drumlins'

In areas where continental glaciers have deposited till, the till has been reshaped into elongated hills known as drumlins. Some drumlins measure as much as 50 m high and 1 km long but most are much smaller. From the side, a drumlin looks like an inverted spoon with the steep end on the side from which the glacial ice advanced and the gently sloping end pointing in the direction of ice movement

(Antrim County, Michigan)

DRUMLIN SWARM, Strangford lough, Co. Down

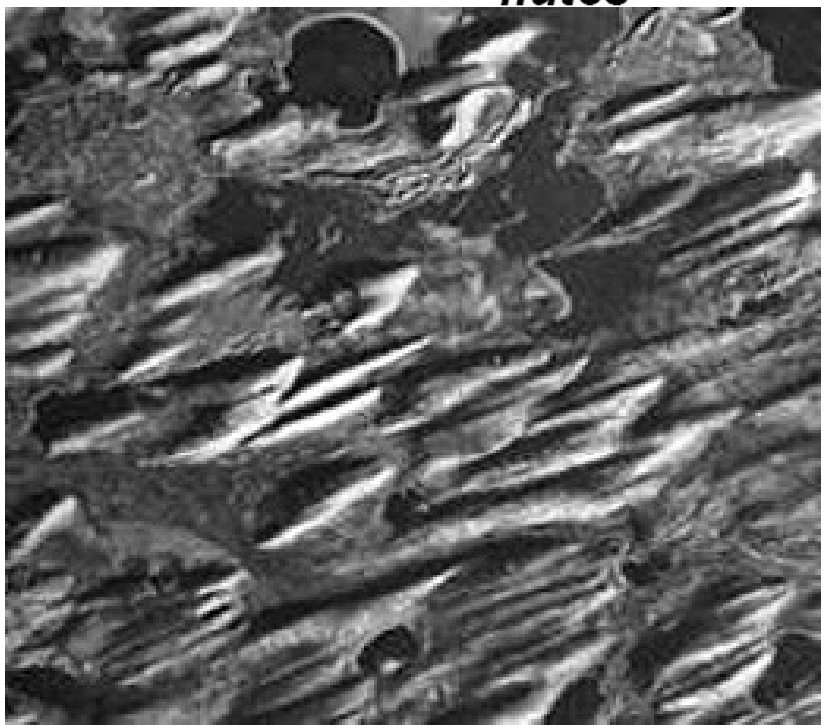
Drumlins

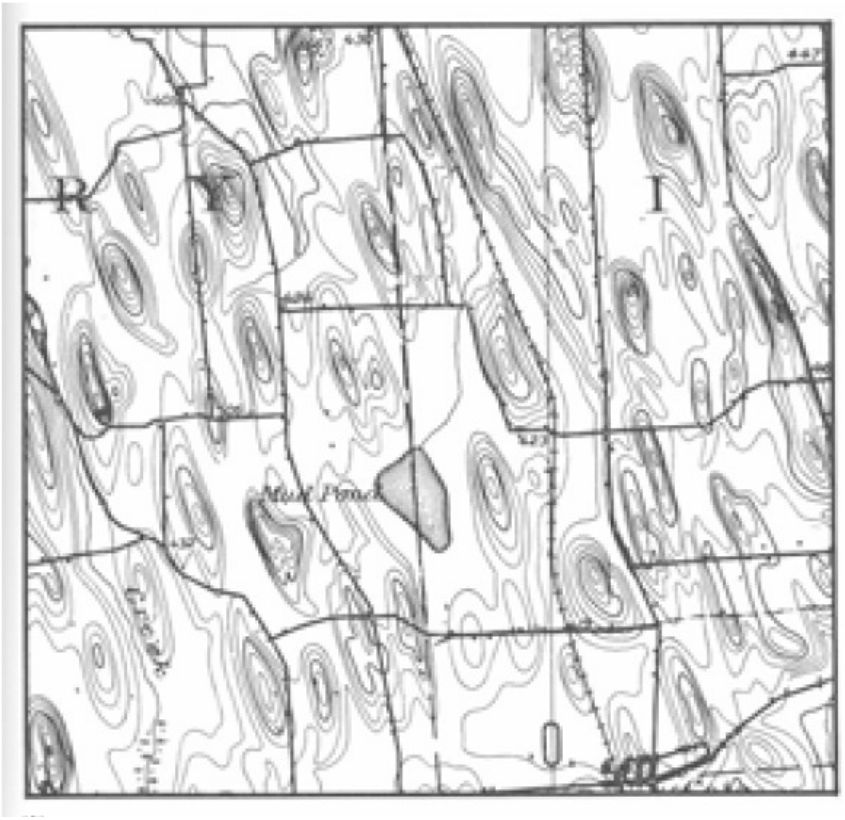
Elliptical hills oriented in the direction of ice movement

Created when a glacier overrides and reshapes preexisting glacial drift

Drumlins

- Streamlined landform of deformed till oriented parallel to ice flow direction
- Taper downglacier in height and width
- Small-scale (~<1 m) forms are called ***flutes***





Melt water landforms

Eskers

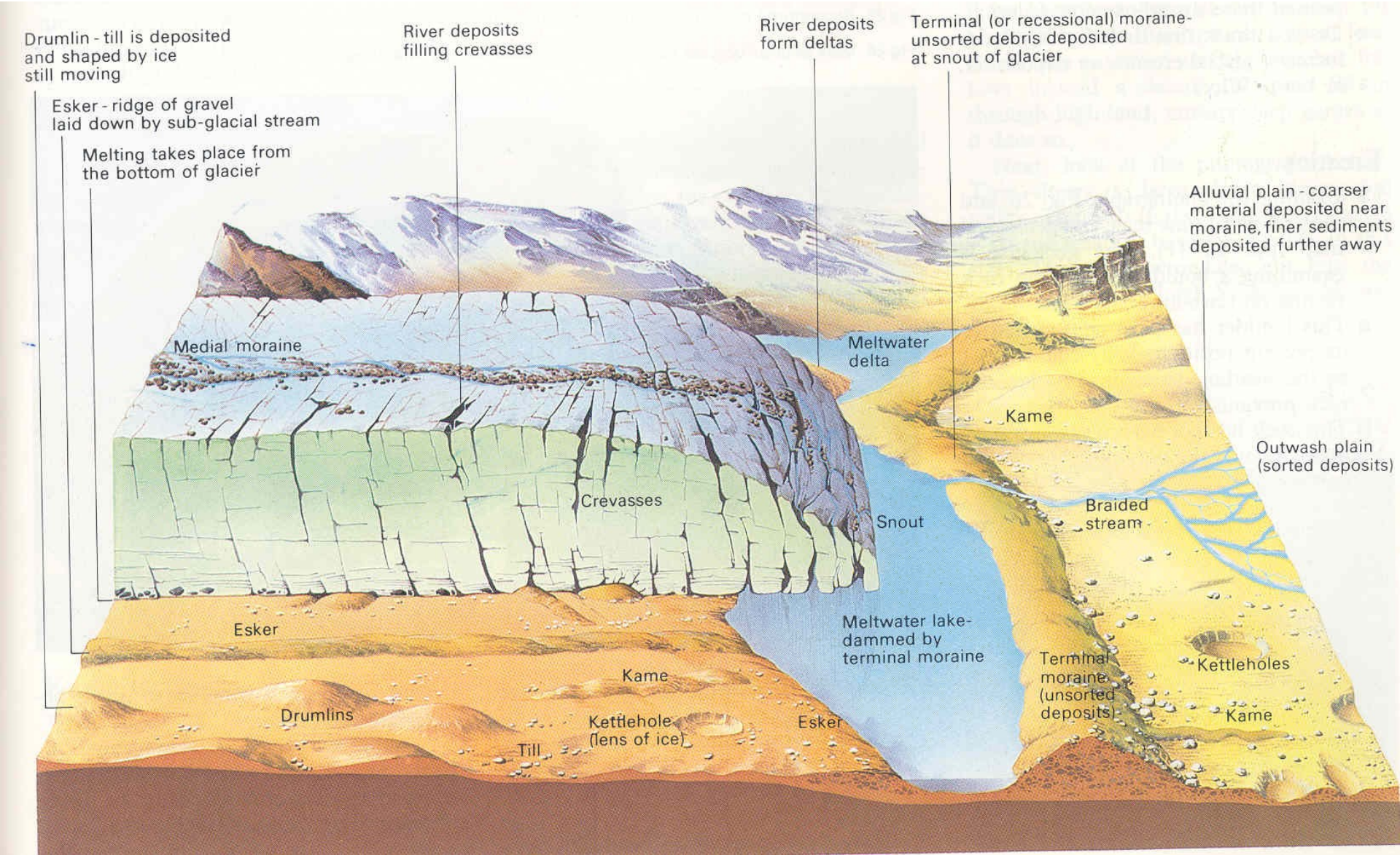
meandering ridges of stratified drift deposited in tunnels in the ice

Eskers - a long, narrow, and often sinuous ridges of stratified drift

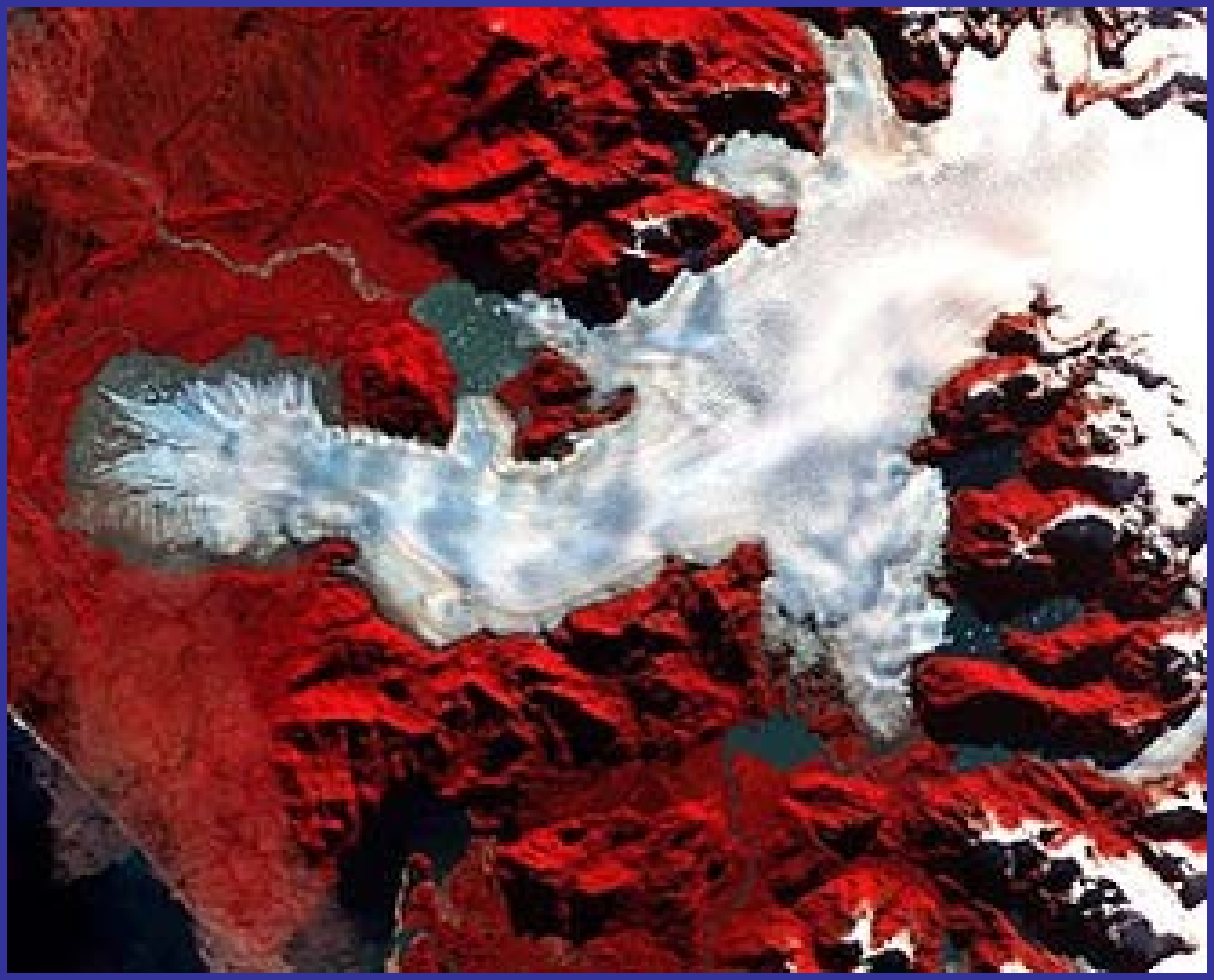
- formed by glacial melt streams flowing in tunnels beneath a stagnant glacier

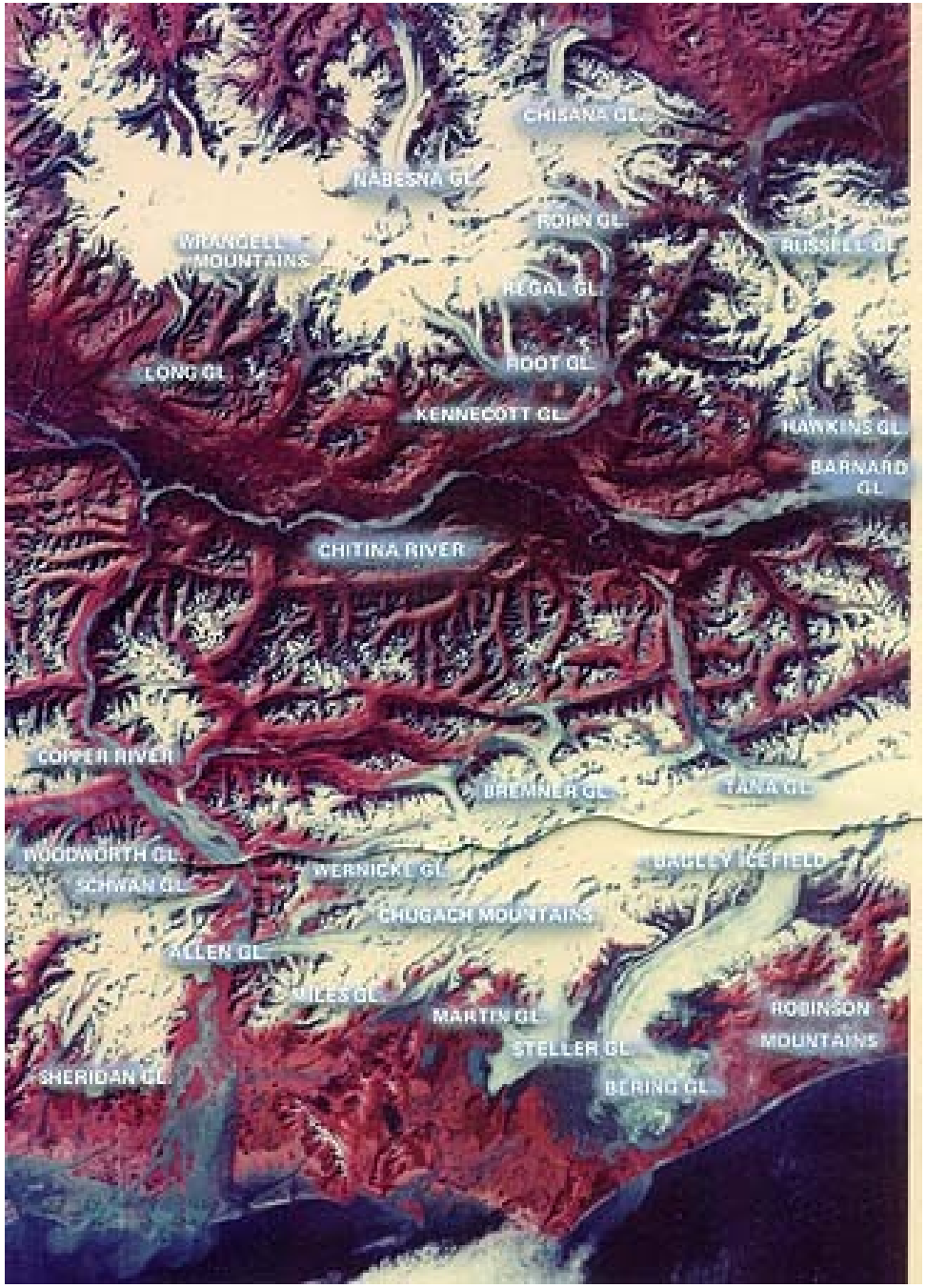
Outwash plain

valleys floors and undulating plains formed in outwash, sand and gravel washed out from glaciers by melt water


Drumlin - till is deposited and shaped by ice still moving
Esker - ridge of gravel laid down by sub-glacial stream
Melting takes place from the bottom of glacier
River deposits filling crevasses
River deposits form deltas
Terminal (or recessional) moraine - unsorted debris deposited at snout of glacier
Alluvial plain - coarser material deposited near moraine, finer sediments deposited further away
Medial moraine
Meltwater delta
Kame
Outwash plain (sorted deposits)
Crevasses
Snout
Braided stream
Esker
Meltwater lake - dammed by terminal moraine
Kame
Terminal moraine (unsorted deposits)
Kettleholes
Drumlins
Kettlehole (lens of ice)
Esker
Kame
Till

In the southern hemisphere glaciers occur in New Zealand and in South America, as this ASTER view of a mountain (valley-filling) glacier in the Andes displays so well (the time of the year is the southern summer [around December])





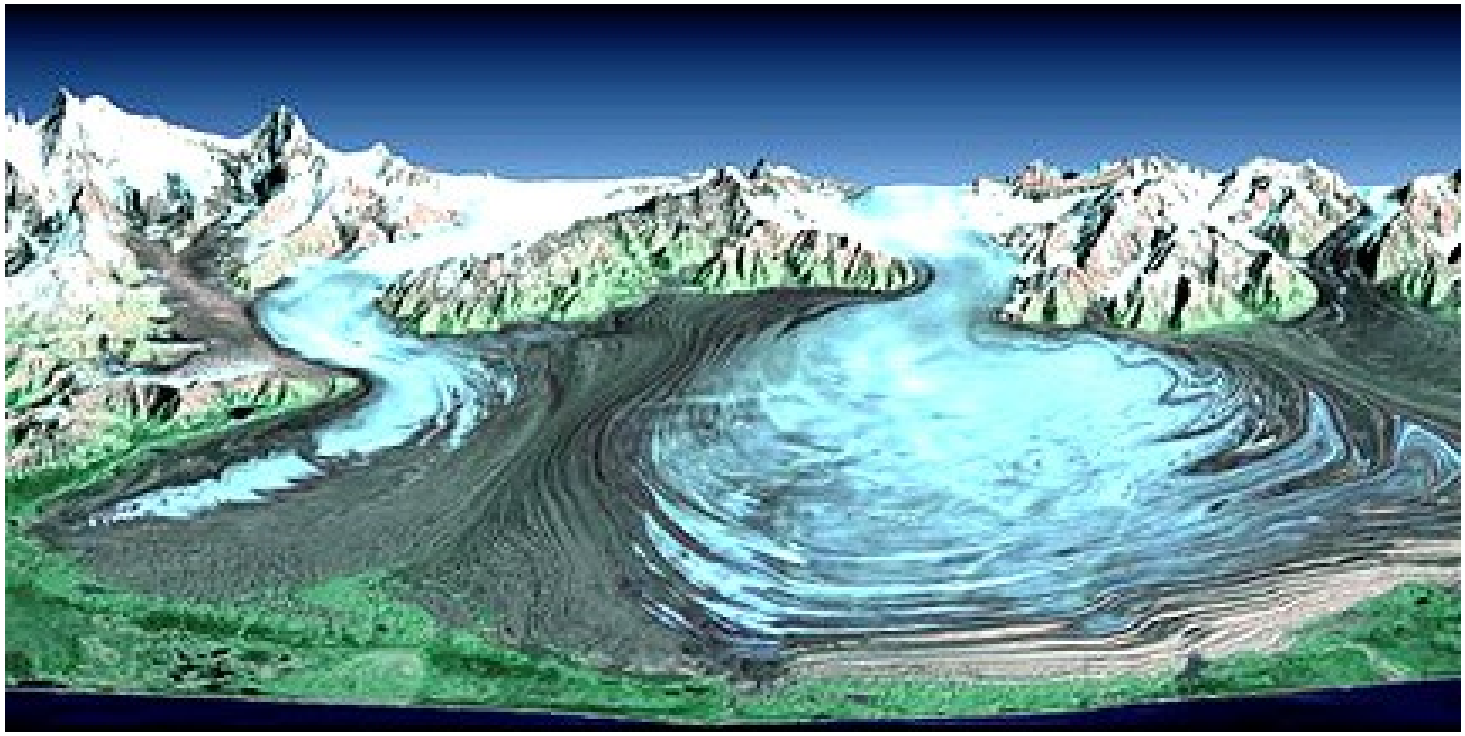
The image mosaic below shows typical alpine or mountain glaciers developed from snow fields covering the higher elevations of parts of the Wrangell and Chugach mountains of southeast Alaska.

Note the dark streaks in some of these piedmont glaciers. These are medial and lateral moraines (glacial debris that may become rock deposits). The reds in the scene are mostly tundra vegetation.

Along the southern coast of Alaska is a famous active glacier known as the Malaspina Glacier. The Landsat subscene below shows a series of internal moraines on the glacier and a prominent wide lateral moraine to the west (left).

The perspective view of this glacier as it creeps towards the Gulf of Alaska, made by combining Landsat and STRM data, shows it in context with its mountain source:

Glaciers tend to have black streaks on their surfaces - these are medial moraine deposits formed as rock falls loose at the head of the glacier and continues this process over the years, so that the debris are strung out as streaks that move over the years.



The Bear glacier in the Denai Peninsula of Alaska shows a prominent medial moraine.

As it reaches an ocean inlet, ice breaks off to form small icebergs that could become a hazard if they reach the open sea.

This IKONOS image has high enough resolution to show crevasses formed by differential movement of the ice mass

Piedmont Glaciers: Fans or lobes of Ice that form where valley glacier spread out to adjacent plains

Piedmont Glacier

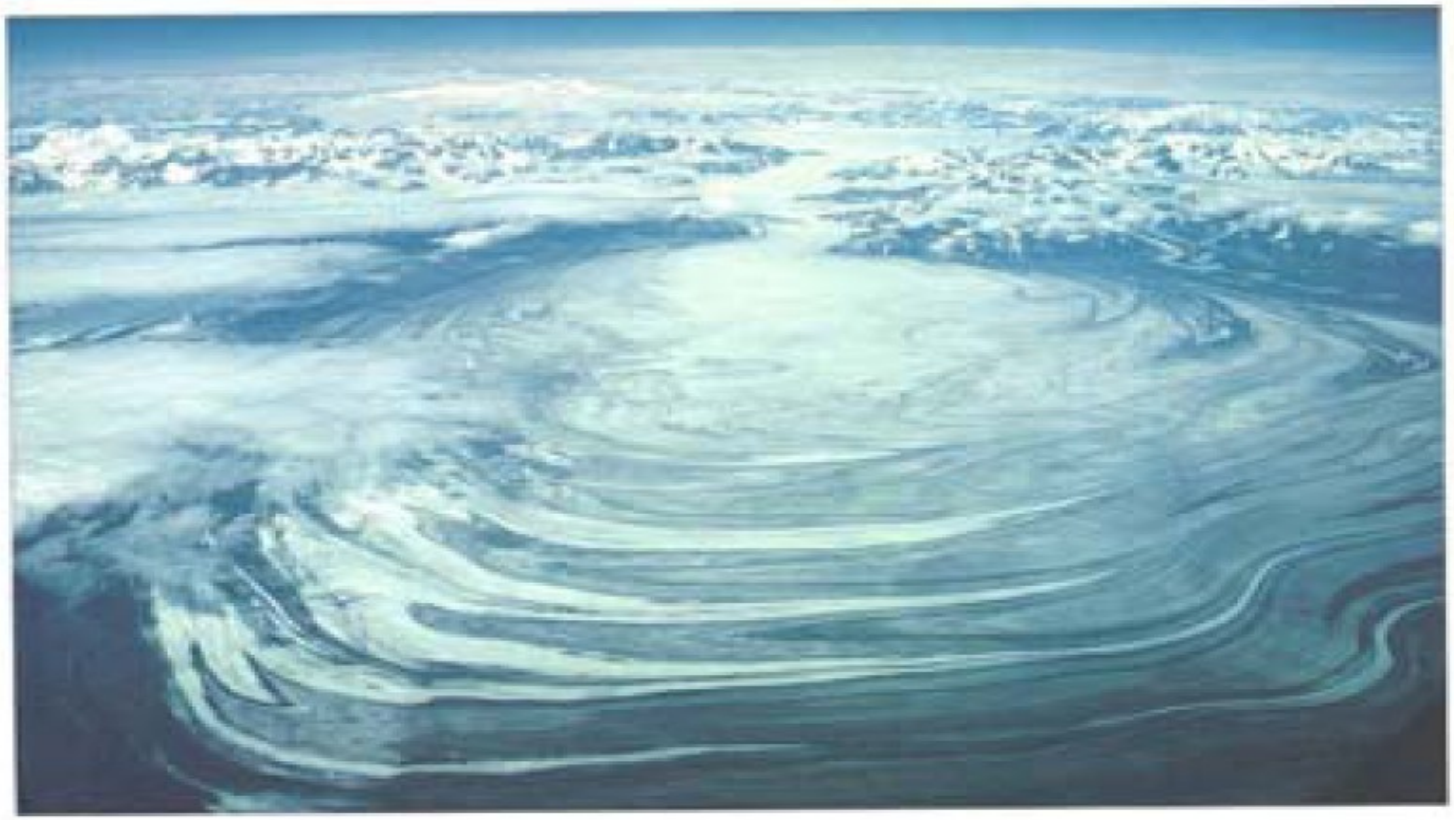
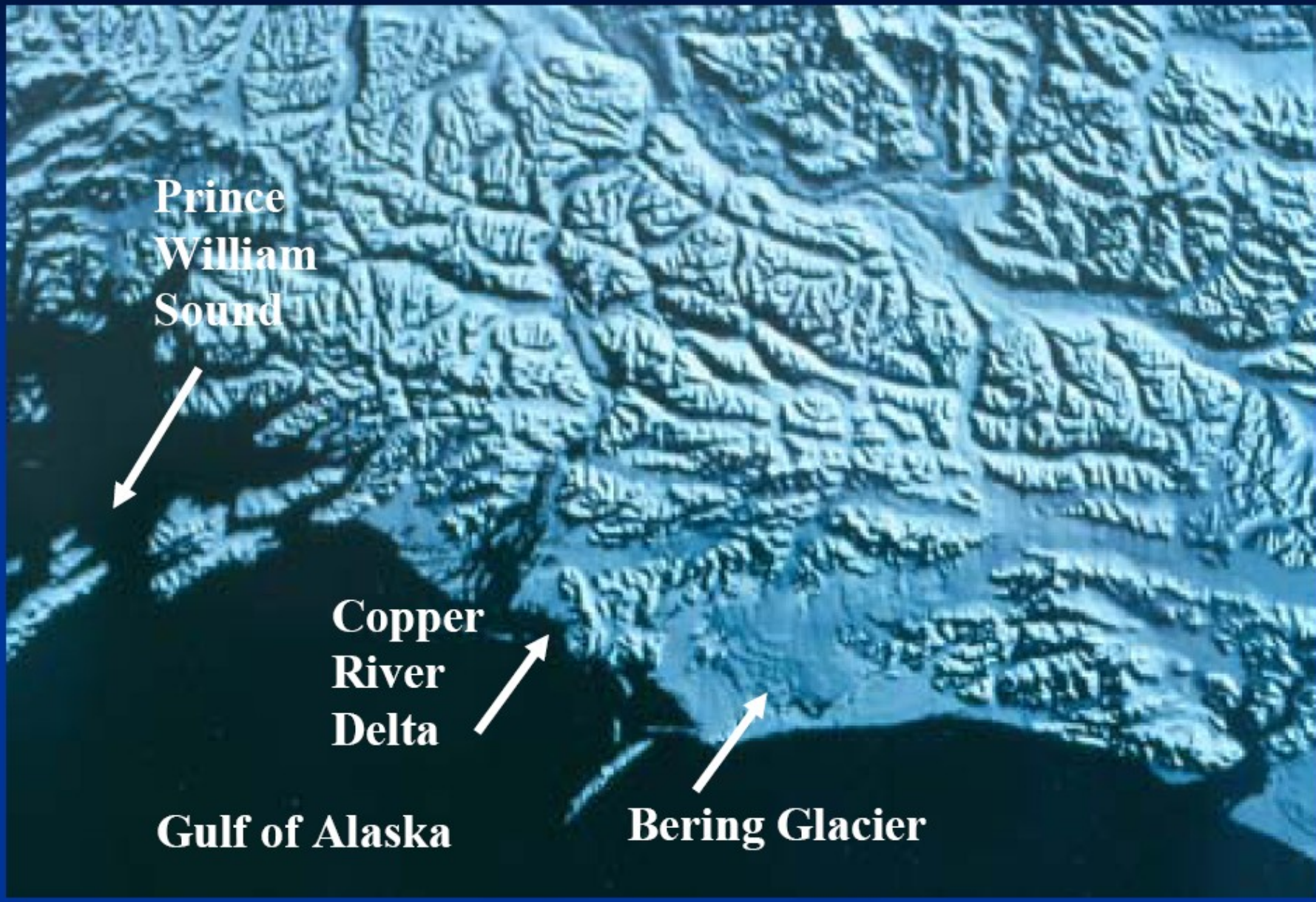


Fig. 1.23 (Plate 5) The piedmont lobe of the Malaspina Glacier, Alaska, showing the spectacular fold structures produced by ice flow into the lowlands. (Photo: Michae Hambrey)

From Benn and Evans. Glaciers and Glaciation, Arnold.

Piedmont Glacier



GLACIAL HAZARDS

Glacial Hazards

- Glacier floods
- Ice avalanches
- Glacier advance and retreat
- Periglacial debris flows
- Rockfall
- Glacier-clad volcanoes
- Process interactions

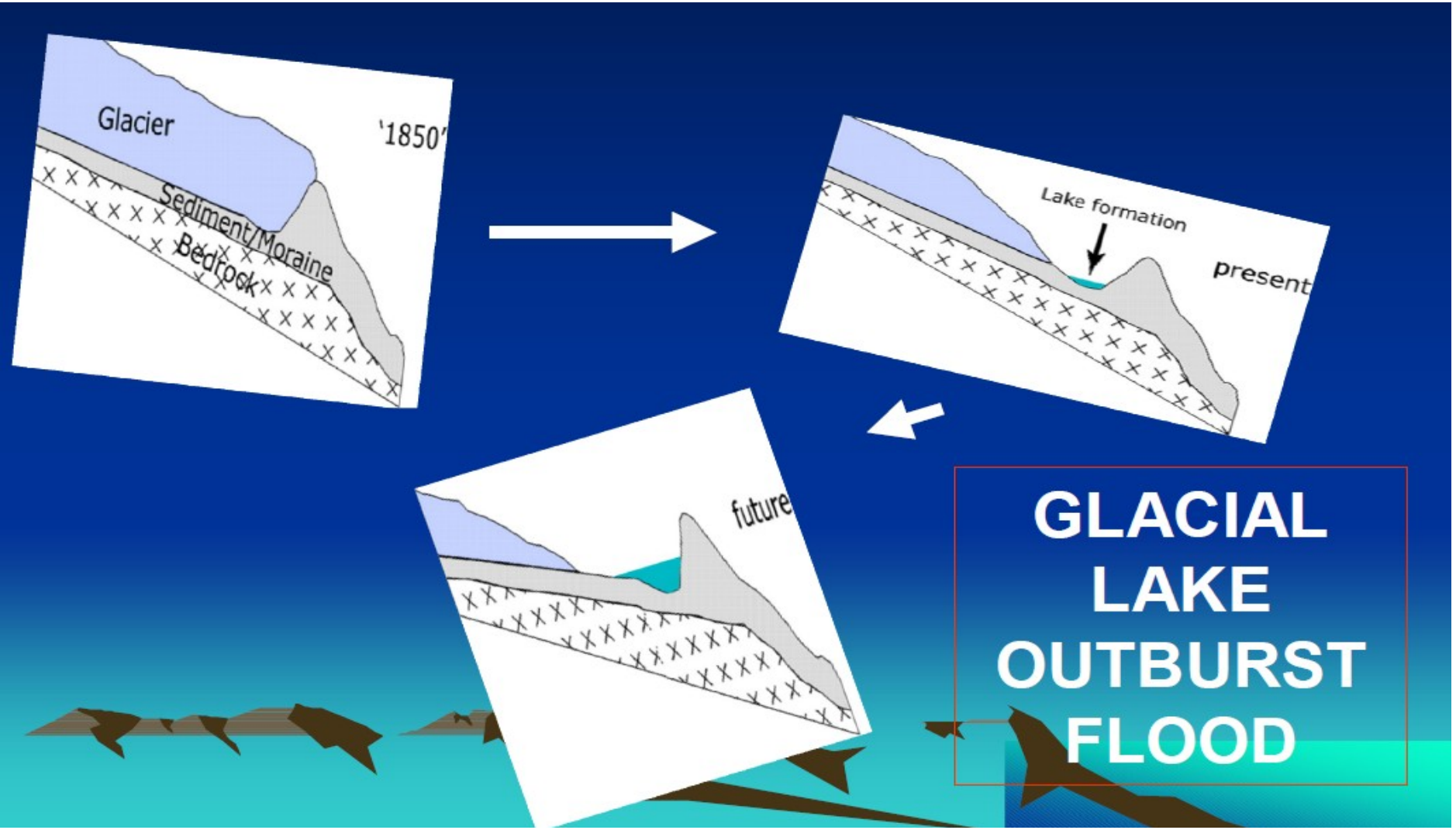
Glacier floods

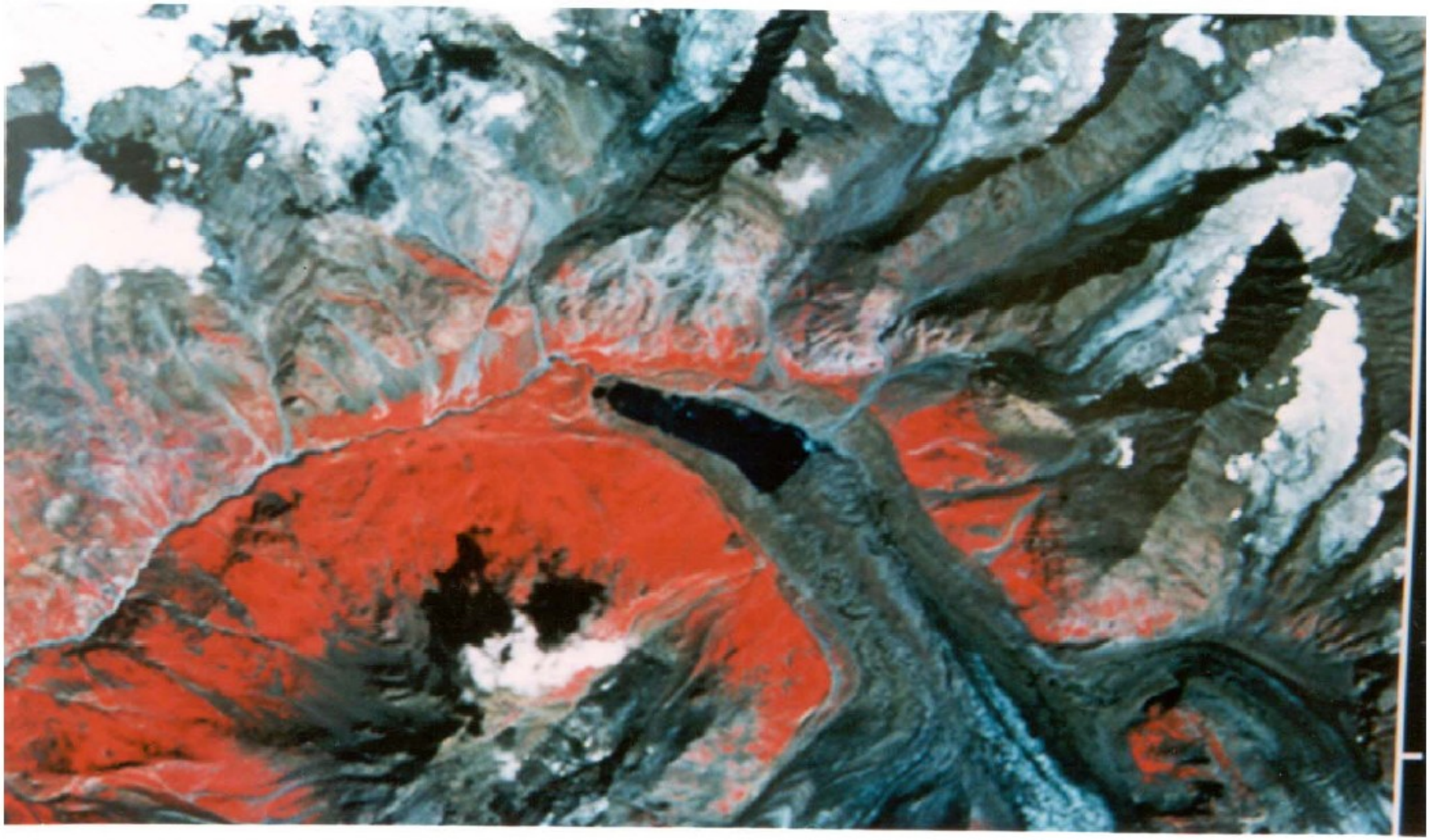
Generally, glacier floods represent the largest and most extensive glacial hazard, i.e., the hazard with the highest potential for disaster and damage

A GLOF (Glacier Lake Outburst Floods, GLOF) is characterized by a sudden release of a huge amount of lake water that rushes along the stream channel downstream in the form of dangerous flood waves.

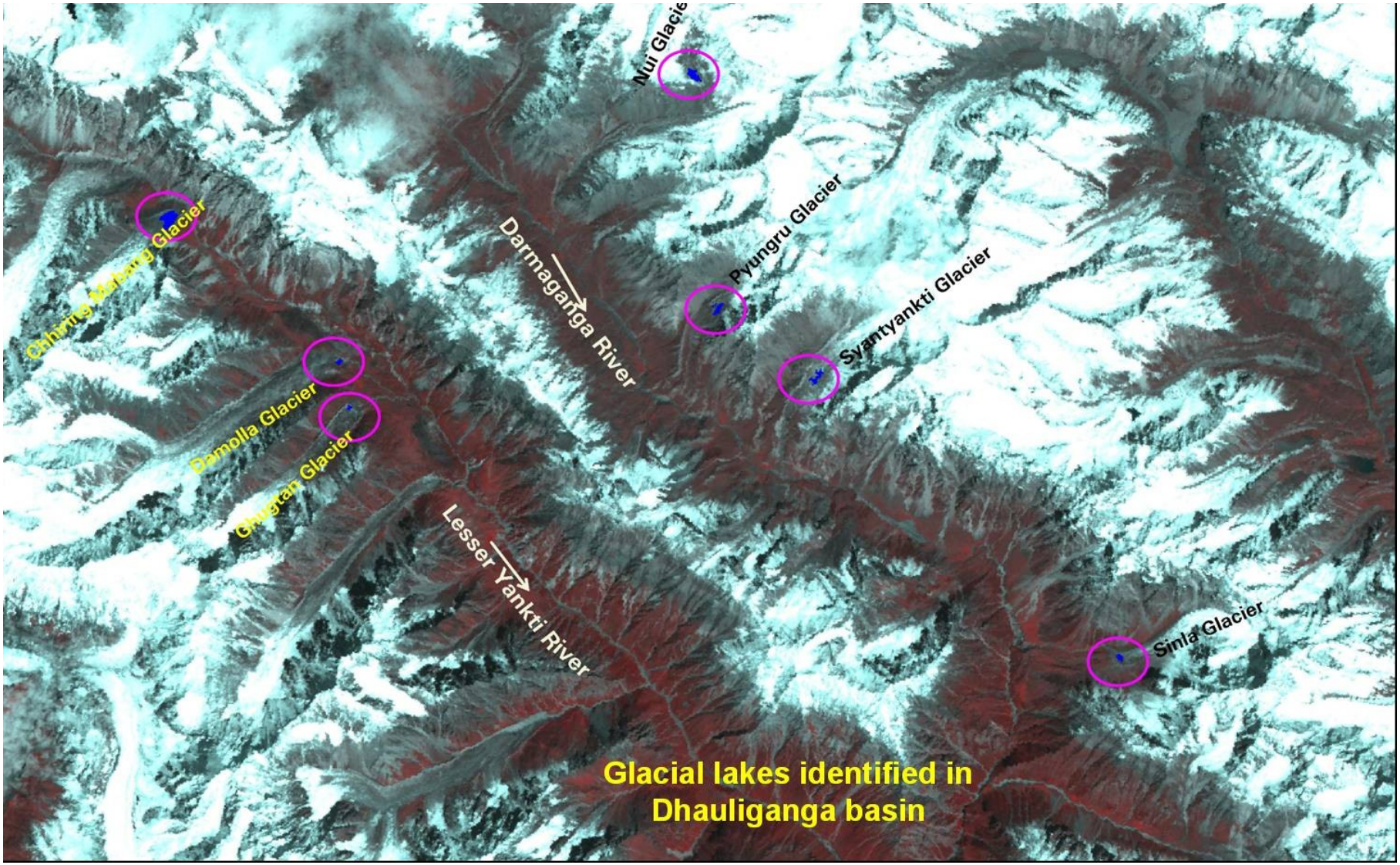
These floods waves comprise of water mixed with morainic materials and cause devastating consequences for riparian communities, hydropower stations and other infrastructure.

The severity of flood wave depends upon the amount of water released, debris load and on basin characteristics of the watershed. Discharge rates of such floods are typically several thousand cubic meters per second.


Glacier
'1850'
Sediment/Moraine
Bedrock
Lake formation
present
future
GLACIAL
LAKE
OUTBURST
FLOOD



SATELLITE VIEW OF MORAINE DAMMED LAKE NEAR THE SNOUT OF GEEPANG GATH GLACIER IN THE CHANDRA RIVER BASIN,HIMACHAL PRADESH


Nui Glacier
Darmaganga River
Pyungru Glacier
Syantyankti Glacier
Chhiring Mabang Glacier
Damolla Glacier
Ghurgan Glacier
Lesser Yankti River
Sinla Glacier
Glacial lakes identified in
Dhauliganga basin

Ice avalanches

They are flows which move under the influence of gravity

They can be channelized or unconfined

In this sense, they are similar to pyroclastic flows, debris flows, etc

Direct effects:
- impact
- burial

Indirect effects:
- tsunamis generated if an avalanche enters a lake

Avalanche zones

a) Starting zone: where an avalanche is initiated

b) Avalanche track : where it goes

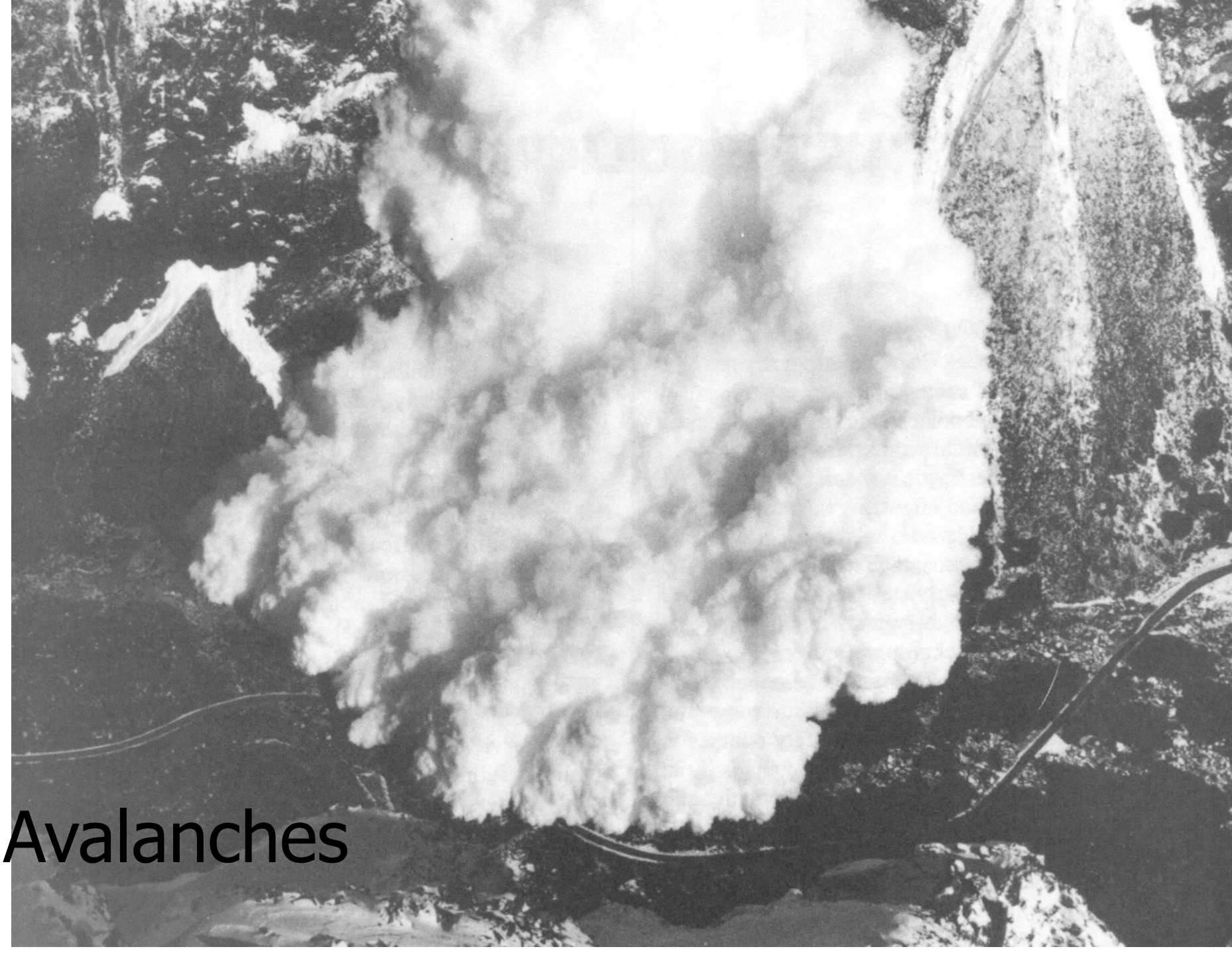
c) Runout area: where it dissipates

Fs = Safety Factor

Fs = (shear strength)/(shear stress)

shear strength: internal resistance to movement
shear stress: force causing movement parallel to slope; increases with slope angle

If Fs is less than 1, then the slope is unstable and prone to failure



Avalanches

Glacier retreat and formation of Glacial Lake

The formation and growth of glacier lakes is a phenomenon closely related to deglaciation.

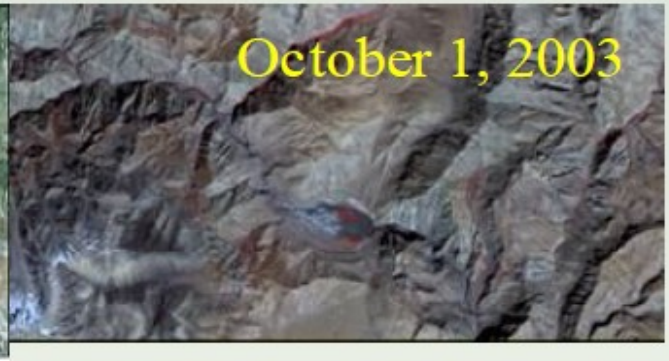
Valley glaciers generally contain supra-glacial ponds. Due to warming climate, these ponds grow bigger and merge.

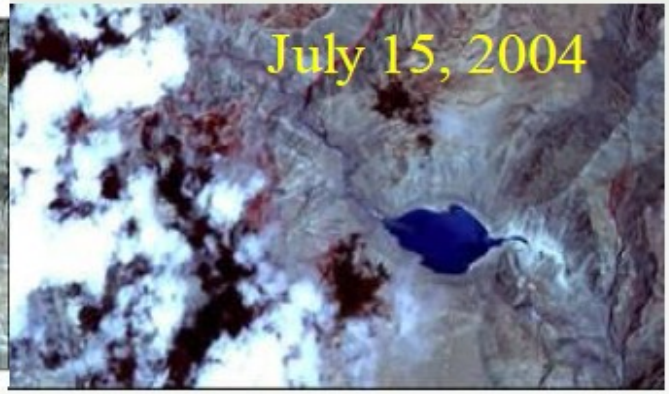
This process is accelerated by rapid retreat of glaciers. As the glacier retreats it leaves a large void behind.

The ponds occupy the depression earlier occupied by glacial ice.

The moraine walls that act as dams are structurally weak and unstable and under go constant changes due to slope failures, slumping, etc. and are in danger of catastrophic failure, causing glacier lake outburst floods (GLOFs). Principally, a moraine dam may break by the action of some external trigger or self-destruction.

Landslide Damburst





Landslide Dam Lake in Pare Chu Tibet Autonomous Region, China – 35 km upstream of India Sutlej basin

Periglacial debris flows

Periglacial debris flows in combination with retreating glaciers, large and steep reservoirs of loose sediment (mainly of morainic origin) can become exposed and then represent a potential source of debris flows.

Analysis of the numerous debris-flow events in the Swiss Alps in 1987 has shown that about 50% of all events (with volumes larger than 1000 m3) originated in areas of loose sediment which have been uncovered in connection with the glacier retreat since 1850

Periglacial debris flows are not only released from glacial forefields but also from marginal permafrost sites, from the scree of debris cones and rock-glacier fronts.

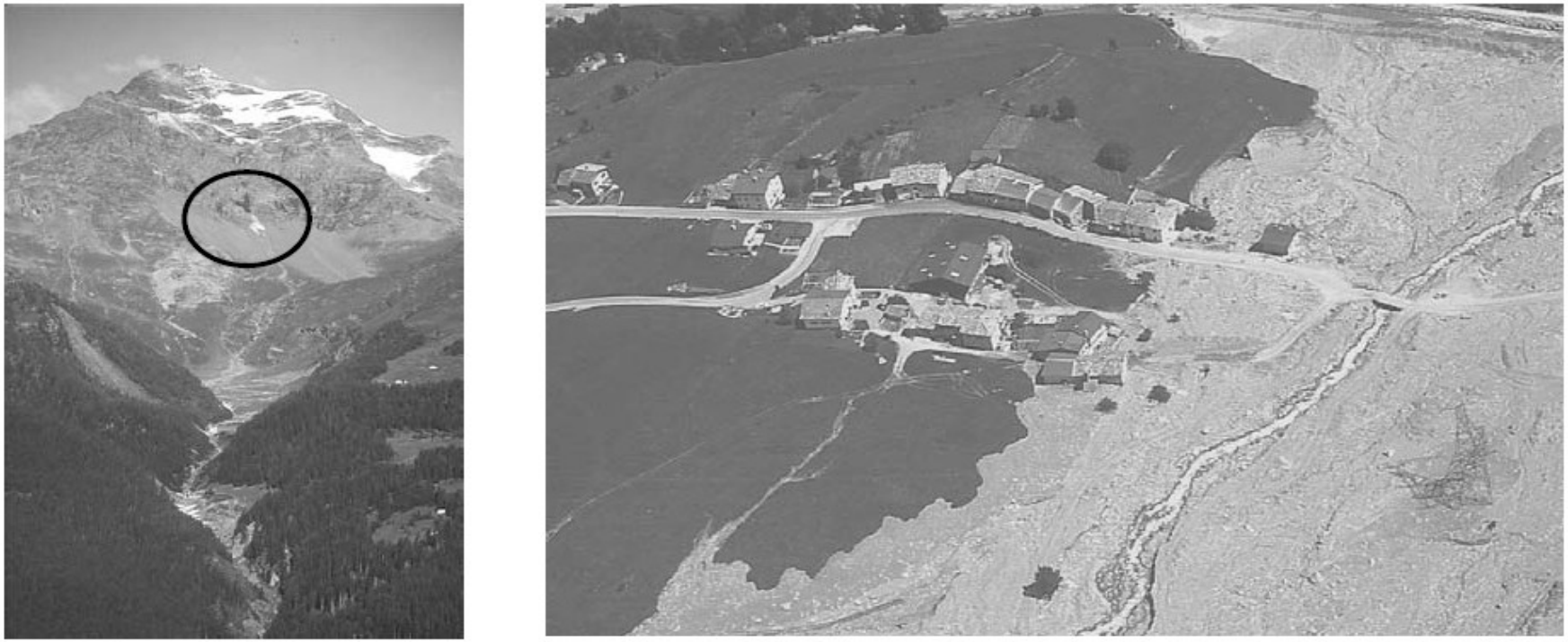


Fig. 4: One of the major flood disasters in the Swiss Alps in 1987 was related to a periglacial debris flow from the Varuna valley (southern Swiss Alps). The debris flow started from a talus slope below Varuna glacier (left image, indicated by circle), damaged the settlement of Privilasco by sediment deposition on the fan (right image), and finally dammed the main river valley. Subsequent flooding caused severe damages of about EUR 30 mill. in the city of Poschiavo (photos: W. Haeberli).

Rock fall

In glacial and periglacial environments, the significance of rockfall relates to the interaction with glacier retreat and permafrost changes, combined events with ice avalanches, and enlarged runout on glacier and snow surfaces.

Glacier retreat may induce changes in the stress field in rock walls, leading to destabilization processes

Shear laboratory tests have shown that a rise in ground temperature may result in a reduction of the shear capacity of ice-bonded discontinuities and eventually in a decrease in slope stability

Fig. 5: Rockfall at the southwest face of the Matterhorn in August 2003, at about 3800 m a.s.l. near Carrel alpine hut. The event is one out of a rockfall series in the extraordinarily hot summer 2003, originating in permafrost areas (photo: L. Trucco).

Glacier-clad volcanoes

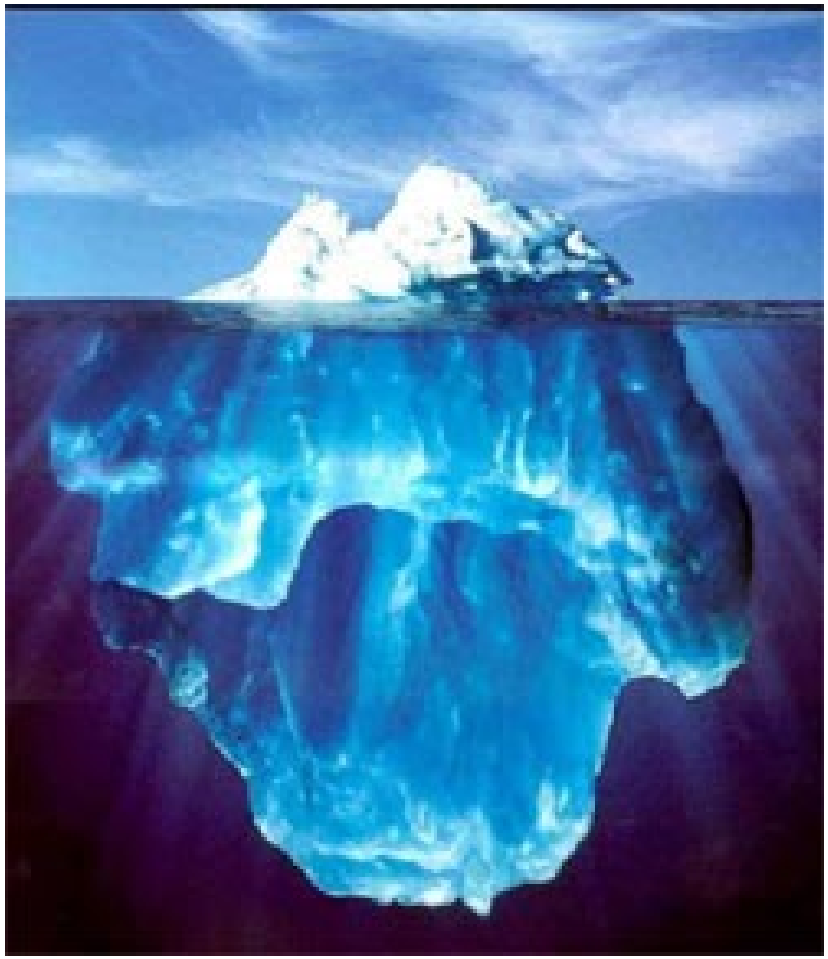
On a global level, glacier-clad volcanoes represent a further major glacier-related hazard.

For instance, lahars (volcanogenic debris flows) can impact downstream areas at a distance of more than 100 km.

The investigation of glacier-clad volcanoes was intensified and reinforced following the eruption of Mount St. Helens (Washington, USA) in 1980 and the Nevado del Ruiz catastrophe (Colombia) in 1985

Fig. 6: Eruption of Popocatépetl volcano, central Mexico, with ash fallout on Ventorillo/Noroccidental glacier (marked by circle, photo: A. Boneta).

Icebergs

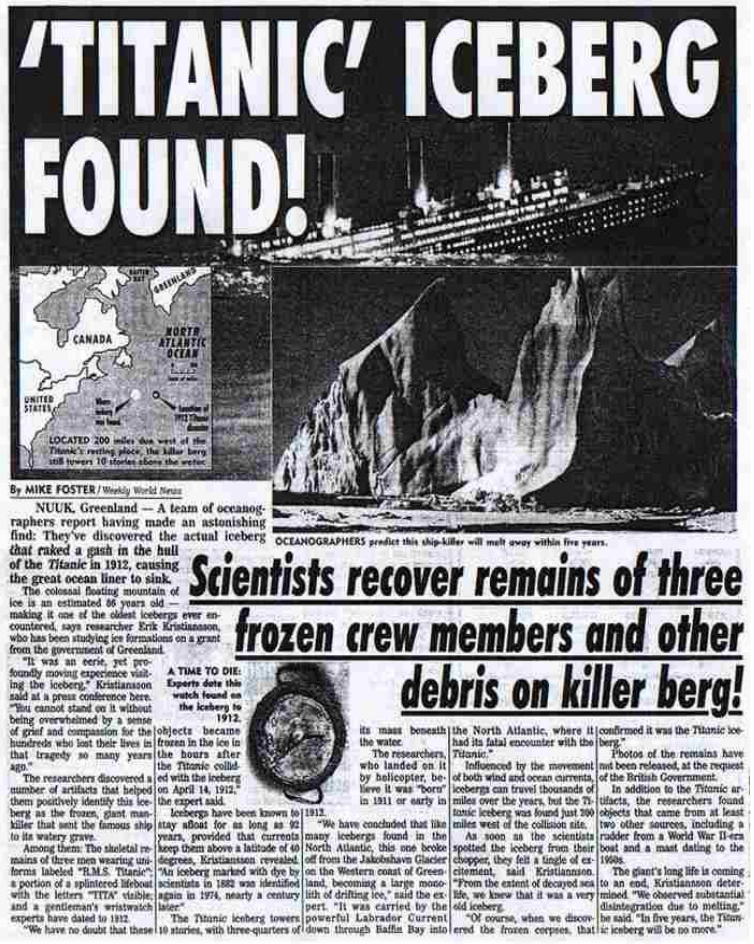


- Glaciers vs. icebergs
- Glaciers move over land and when they hit water they become an iceberg.
- 10,000 icebergs form every year from Greenland.

Icebergs

- Only about 10 percent of an iceberg is visible.
- 90% of an iceberg lies below the surface.
- The underwater part is a hazard to ships because it is often much wider than the visible part of the iceberg.

Icebergs



'TITANIC' ICEBERG FOUND!

By MIKE FOSTER / Weekly World News

NUUK, Greenland — A team of oceanographers report having made an astonishing find: They've discovered the actual iceberg **that raked a gash in the hull of the *Titanic* in 1912, causing the great ocean liner to sink.**

The colossal floating mountain of ice is an estimated 86 years old — making it one of the oldest icebergs ever encountered, says researcher Erik Kristiansson, who has been studying ice formations on a grant from the government of Greenland.

"It was an eerie, yet profoundly moving experience visiting the iceberg," Kristiansson said at a press conference here. "You cannot stand on it without being overwhelmed by a sense of grief and compassion for the hundreds who lost their lives in that tragedy so many years ago."

The researchers discovered a number of artifacts that helped them positively identify this iceberg as the frozen, giant mankiller that sent the famous ship to its watery grave.

Among them: The skeletal remains of three men wearing uniforms labeled "R.M.S. Titanic"; a portion of a splintered lifeboat with the letters "TITA" visible; and a gentleman's wristwatch experts have dated to 1912.

"We have no doubt that these objects became frozen in the ice in the hours after the *Titanic* collided with the iceberg on April 14, 1912," the expert said.

Icebergs have been known to stay afloat for as long as 92 years, provided that currents keep them above a latitude of 40 degrees, Kristiansson revealed.

"An iceberg marked with dye by scientists in 1882 was identified again in 1974, nearly a century later."

The *Titanic* iceberg towers 10 stories, with three-quarters of its mass beneath the water.

The researchers, who landed on it by helicopter, believe it was "born" in 1911 or early in 1912.

"We have concluded that like many icebergs found in the North Atlantic, this one broke off from the Jakobshavn Glacier on the Western coast of Greenland, becoming a large monolith of drifting ice," said the expert. "It was carried by the powerful Labrador Current down through Baffin Bay into the North Atlantic, where it had its fatal encounter with the *Titanic*."

Influenced by the movement of both wind and ocean currents, icebergs can travel thousands of miles over the years, but the Titanic iceberg was found just 200 miles west of the collision site.

As soon as the scientists spotted the iceberg from their chopper, they felt a tingle of excitement, said Kristiansson. "From the extent of decayed sea life, we knew that it was a very old iceberg.

"Of course, when we discovered the frozen corpses, that confirmed it was the *Titanic* iceberg."

Photos of the remains have not been released, at the request of the British Government.

In addition to the *Titanic* artifacts, the researchers found objects that came from at least two other sources, including a rudder from a World War II-era boat and a mast dating to the 1950s.

The giant's long life is coming to an end, Kristiansson determined. "We observed substantial disintegration due to melting," he said. "In five years, the Titanic iceberg will be no more."

OCEANOGRAPHERS predict this ship-killer will melt away within five years.

Scientists recover remains of three frozen crew members and other debris on killer berg!

A TIME TO DIE: Experts date this watch found on the iceberg to 1912.

- The International Ice Patrol was set-up to track icebergs alter the Titanic disaster.
- They use ships, planes, and satellites to track icebergs.
- Warnings by the patrol have saved many people from disasters like the Titanic.

At 2:17 A.M., the *Titanic*'s stern rose out of the water, reaching a near vertical position before the great ship disappeared under the sea. From the lifeboats, passengers heard a hideous noise as all the contents of the ship crashed forward. Several survivors reported seeing the ship begin to break apart.